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Transportation and Dispersal of Biogenic Material in the Nearshore Marine Environment.

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TRANSPORTATION AND DISPERSAL OF BIOGENIC MATERIAL IN THE NEARSHORE MARINE ENVIRONMENT

A DISSERTATION

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ABSTRACT

An investigation of sediments and biota was undertaken within a small area of Gulf of Mexico coastal waters near the village of Destin on the Florida panhandle. The main objectives of the study were to determine the efficiency of waves and currents in transporting and dispersing biogenic material in the nearshore open-marine environment, and to assess the applicability of fragmentation, preservation, and disarticulation as criteria for paleoecologic interpretation of the death assemblage. The study area includes the steeply sloping shoreface and a portion of the offshore sand plain. Several lines of traverse were established along which sampling and observation proceeded.

Terrigenous sediments are primarily quartz sands which are distributed in textural zones which parallel the coast: 1) fine sands of the upper shoreface derived from the present westward drift system; 2) medium sands of the lower shoreface and inner offshore sand plain possibly derived from erosion of the underlying strata of the shoreface; and 3) coarse sands of the offshore sand plain deposited as Early Holocene alluvium(?). A submerged outcrop of Pamlico(?) age, quartzose lime grainstone contributes fine quartz grains, which are carried northward to form an anomalous fine sand body on the offshore sand plain, and very coarse grains which remain near the outcrop as lag.

Biogenic carbonate increases in percentage in the sediment with water depth from less than one percent on the upper shoreface to a maximum of 17.25 percent near the limestone outcrop. The relationship of modal grain size in the terrigenous and biogenic fractions suggests that sorting under similar hydrodynamic conditions accounts for grain size distributions

of both fractions.

Observation indicates that sediment movement is active at all depths in the research area. Orbital velocities are frequently sufficient to move very coarse biogenic material. A consideration of bed load transport theory suggests that terrigenous sediment grain size is at least in partial adjustment to present conditions of incident wave energy, water depth, and bottom slope in the study area.

The level-bottom biota is distributed in zones which parallel the coast and includes primarily mollusks, echinoids, asteroids, coralline algae, polychaetes, crustaceans, and bryozoans. Of these, mollusks, echinoids, and coralline algae dominate the thanatocoenosis as whole shells and fragmental remains. The limestone outcrop supports a diverse epifaunal association and many boring and cryptic species.

The distribution and composition of fragmental biogenic material reflects adequately the distribution and composition of the living community with some effects of selective preservation. A detailed analysis of the bivalve thanatocoenosis indicates that shells of bivalve species are consistent in distribution with the occurrence of species in the community with the exception of transported accumulations of *Donax variabilis* on the shoreface and relict molluscan assemblages on the offshore sand plain.

Physical aspects of shell preservation, disarticulation, disassociation, and size frequency distribution can be attributed to prolonged exposure in a regime of oscillatory bed load movement. Oscillatory mass transport currents are inefficient as agencies of net transport; oscillatory motion leads to the rapid destruction of shell material. Net transport, predicted by theory, has had little influence on the composition

of the thanatocoenosis. Only where directed currents, such as rip currents, rapidly deposit abundant shells, as in the case of *Donax variabilis*, is the composition of the death assemblage significantly altered.

The thanatocoenosis in the study area forms a basis for the accurate reconstruction of the community with respect to those organisms which contribute skeletal material. However, spurious interpretation may result for the local presence of relict faunal elements.

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INTRODUCTION

General Statement

The reconstruction of ancient sedimentary environments is often based, in part, on known or inferred environmental implications of fossil assemblages and species. However, paleoecologists have long recognized that the thanatocoenosis or death assemblage may not be representative of the biocoenosis or living community. It has been shown that as many as 70 percent of the species present in marine communities leave no preservable remains in the fossil record other than traces of their activities (Johnson, 1964). The thanatocoenosis is inherently biased towards those organisms which possess preservable hard parts. These species must carry most of the available paleoecological information. It is further evident that skeletal material may be transported, redeposited, and modified by physical and biological processes so that its relationship to the original community is obscured.

The study of processes, excluding diagenis alteration, which effect the nature of the thanatocoenosis has been termed biostratinomy (Lawrence, 1968). Biostratinomy seeks to turn a potential information loss for the paleobiologist, in terms of the destruction of community relationships, into a gain in information for the paleoenvironmentalist, as the mode of preservation can be related to environmental conditions at the site of accumulation. This type of investigation must rely heavily on modern analogues, process-response studies, and specifically designed experiments. The efforts of the present study are directed to provide biostratinomic information for the shallow marine nearshore zone.

The degree of correlation that exists between the biocoenosis and

the thanatocoenosis as regards preservation of orientation, community structure, and species composition can be attributed to the magnitude and duration of energy input at the locus of biogenic accumulation. Two sources of energy can be identified in the shallow marine environment; 1) hydrodynamic and 2) biologic.

Hydrodynamic energy is expressed in the form of waves and currents which may disturb the bottom over which they pass. The effect of fluid motion of sufficient velocity includes transportation accompanied by disarticulation, reorientation, abrasion, and winnowing of the subjacent skeletal material. The ability of waves and currents to transport both sediment and biologic material in the littoral zone is well known. Less understood is the degree of effective transportation at water depths below normal wave base and removed from tidal channel influence. Within this environment, virtually no movement of coarser detrital grains, by physical processes, occurs during normal weather conditions but, during storms, oscillatory fluid motion combined with current residuals may result in transport of biologic and clastic detritus across environmental boundaries. The distribution of biogenic remains on the sea floor will then reflect the episodic removal of material from one biotope and its deposition in another.

Of equal or greater importance, particularly in deeper water, is the biologic component of energy input. This input finds its expression in the behavior of organisms which inhabit the site of accumulation and contribute energy to the system in the form of bioturbation. The responses of biogenic material to bioturbation are somewhat similar to those produced by hydrodynamic input, but bioturbation is essentially an *in situ* process of homogenization whereas waves and currents tend to

introduce order in the form of stratification. In quiet water where disturbance of the bottom by waves is infrequent, the activities of burrowers, scavengers, and predators become the dominant influence with regard to the character of accumulated biogenic remains.

An evaluation of the relative importance of these two major modifying agents, as reflected in the thanatocoenosis, is essential to paleoecologic interpretation. The shallow sublittoral zone offshore Destin, Florida, provided an opportunity to study processes operating in a natural system and to assess their influence on the accumulation of the thanatocoenosis.

Research Area

The study site is located in Gulf of Mexico coastal waters off the Florida panhandle, four miles east of the village of Destin, and encompasses an area of about four square miles (Figures 1 and 2). The coast is formed by Moreno Point, a peninsula of the mainland which projects from the east and separates the open Gulf from Choctawhatchee Bay. The white quartz sand beach developed on the Gulf side of Moreno Point is delimited landward by a bluff which, although not well exposed at the research area, rises to a height of 25 feet at Destin and up to 40 feet at the town of Seagrove Beach 20 miles to the east.

Choctawhatchee Bay opens to the Gulf through a narrow pass (Figure 2) which is jettied and maintained by the U. S. Army Corps of Engineers. Choctawhatchee River enters at the east end of the Bay where deltaic infilling is proceeding slowly. The center of the Bay is receiving fine-grained organic rich sediments (Palacas et al., 1968). Aerial photographs reveal well-developed submerged tidal deltas on both the Bay and Gulf side

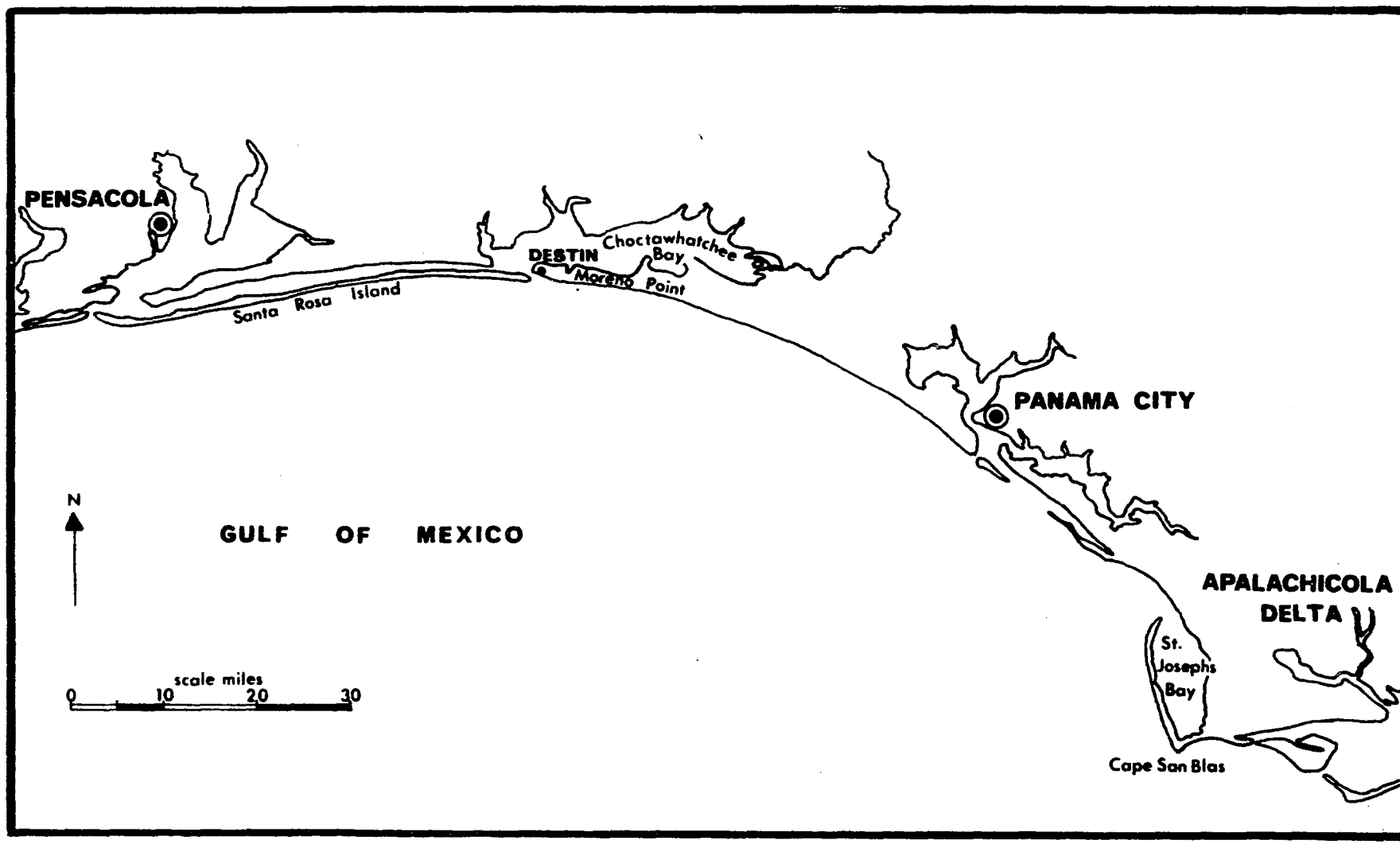


Figure 1. Geography of the Western Panhandle Coast of Florida

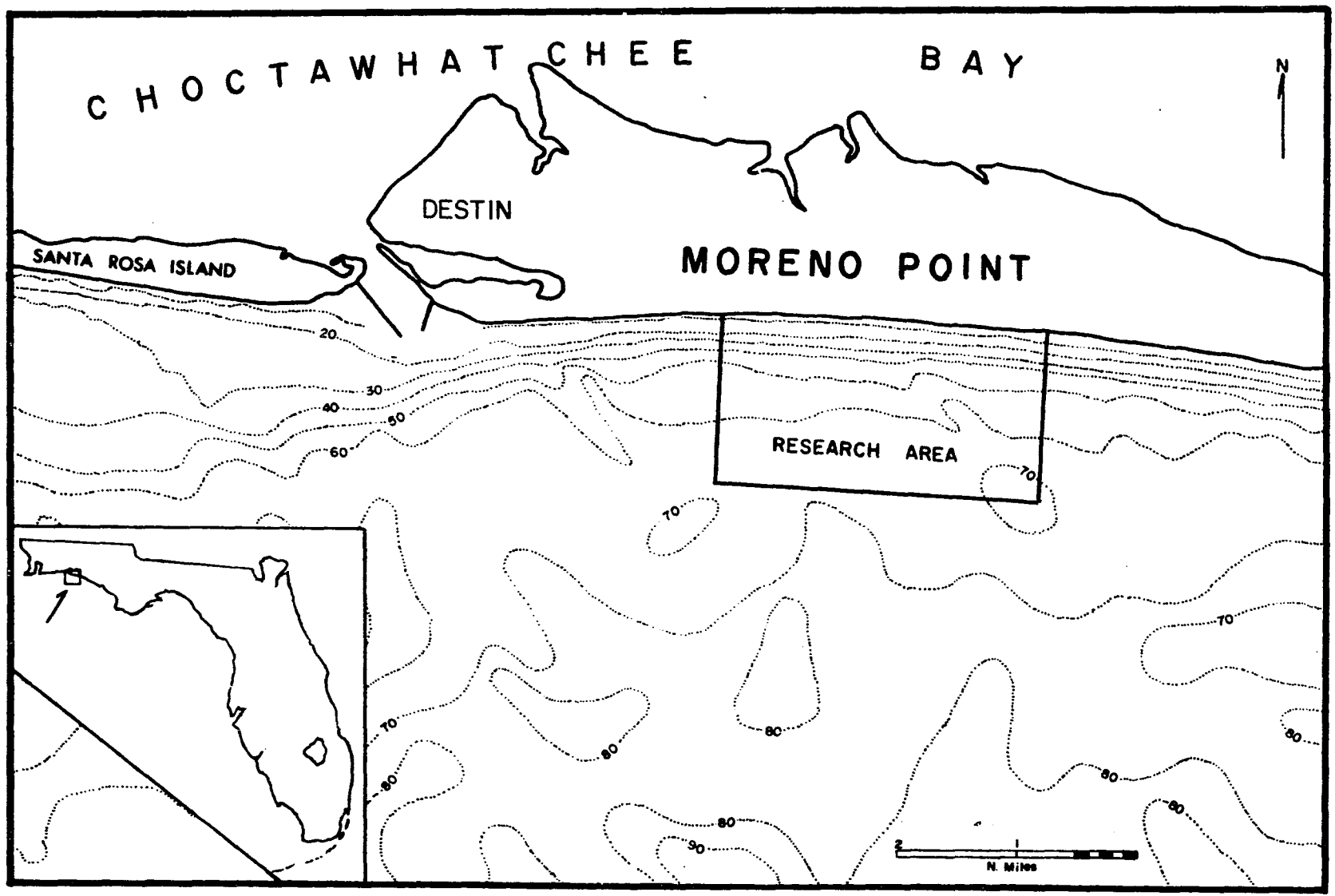


Figure 2. Location of the Research Area on the Florida Panhandle Coast.
Contour Interval - 10 feet

of the pass. The sands of the interior tidal delta are probably derived almost exclusively from the Gulf, supplied by longshore drift, and carried into the Bay by swift flood tide currents.

West of the pass the coast is formed by Santa Rosa Island, a barrier island which is separated from the mainland by a narrow linear lagoon. Santa Rosa Island extends westward 46 miles to Pensacola, Florida, where it becomes part of a complex of spits and smaller bars which extends westward to Mobile Bay.

East of the study area the coast forms a broad arc and trends southeast to intersect the delta of the Appalachicola River. The delta is no longer actively prograding and has undergone considerable erosion by coastal processes. It forms an important source of sand for this part of the Florida coast (Gorsline, 1966).

Water depths in the research area range from mean sea level at the beach to 73 feet in a bathymetric low to the east (Figure 3). The large scale bathymetric map of the area was constructed on the basis of depth gauge readings taken during the course of investigation and is compatible with the general bathymetry displayed by U. S. Coast and Geodetic Survey Chart 1294. A study of detailed bathymetry suggests a two-fold division of the research area; 1) the rather steeply sloping (1.5°) shoreface, to a depth of about 50 feet, and 2) the gently sloping (.1°) offshore sand plain.

The research site was selected to include the area of limestone outcrop shown in figure 3. This lithotope supports a distinctive community of epifaunal, crevice-dwelling, and boring species whose skeletal remains are available for transport and modification by physical and biologic processes. The magnitude and direction of movement of this

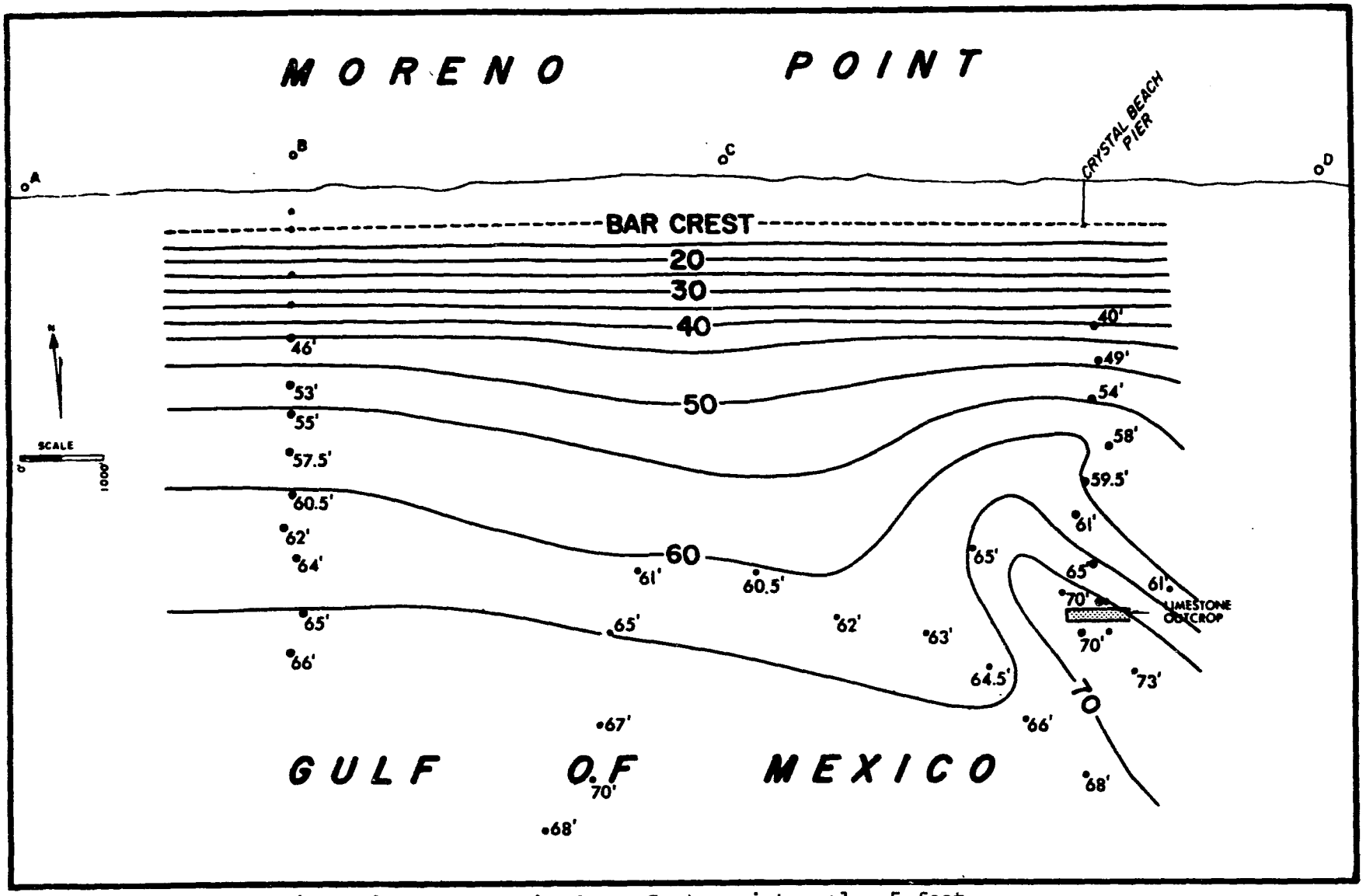


Figure 3. Bathymetric Map. Contour interval - 5 feet.

material onto the adjacent sand plain can be evaluated with considerable confidence. It was believed at the outset that the steep slope of the shoreface would result in compression of community zonation on the shoreface in response to rapid shoaling. In such a situation, where the distribution of these communities could be determined, transportation of shell material could be more easily detected than where broad, less well-defined community zonation existed. Other factors which influenced the selection of the study area included 1) accessibility, 2) previous knowledge of bottom characteristics, 3) visibility compatible with the use of SCUBA.

Previous Biostratinomic Work

Transportation and modification of biogenic material by physical and biologic processes have received considerable attention in the literature. Biostratinomic studies tend to be grouped into two categories; 1) studies concerned with the theoretical or actual response of specific variables to environmental stresses, and 2) studies of natural communities or fossil assemblages and their relationship to the thanatocoenosis.

General theoretical overviews of the subject are provided by Craig and Jones (1966), Boucot (1953), Craig (1953), Fagerstrom (1964), Johnson (1960), Lawrence (1968), Craig and Oertel (1966), and Kurten (1964). Laboratory investigation of the movement of shells by currents include Johnson (1957), Kelling and Williams (1967), Menard and Boucot (1951), and Nagle (1967). Controlled experiments or quantitative observation in natural marine environments were made by Driscoll (1967, 1970), Clifton (1971), Lever (1966), Martin-Kaye (1951), Emery (1968b), and Behrens and Watson (1969). The significance of size-frequency distribution and

population dynamics is discussed by Hallam (1967), Craig (1967), Craig and Hallam (1967), and Sheldon (1965).

Studies in natural settings include those of Warme (1969, 1971), Lawrence (1968), Johnson (1962a, 1965), Cadee (1968), Boucot et al.,(1958), McAlester et al.,(1964), Straaten (1952, 1956), Valentine (1961), Wilson (1967), and Boillot (1964). These investigations are largely confined to bay or lagoonal communities and settings no doubt for reasons of accessibility. Because much of the geologic record consists of sediments deposited in open marine environments, it is of interest to extend biostratinomic studies to the continental shelf.

Quantitative experiments concerning the movement of shell material by currents have not produced a satisfactory predictive theory due to the complexity of the relationship of shape, size, and orientation to the critical current velocity and the maintenance of movement. However, they do form a basis for certain qualitative statements concerning the fate of biogenic material in a hydrodynamic regime.

Other pertinent literature will be reviewed in appropriate sections of this report.

Approach

The degree of transportation of shell material may be assessed directly by comparison of the distriburion of living communities and skeletal debris derived from them. This can be accomplished only where abundant living and dead biogenic material is available for transport and, most importantly, for collection. These conditions are satisfied by the epifaunal community inhabiting the area of rock bottom mentioned previously (see Figure 3). Accordingly, a detailed study was undertaken

to determine the distribution of living and dead biogenic material adjacent to this area under the working hypothesis that the efficacy of wave transport would be reflected in the distance to which the remains were carried out onto the surrounding sand plain.

The situation on the sand plain itself is quite different and requires an indirect approach which yields somewhat controversial data. Because of the very low numbers of living individuals of all species, the occurrence of skeletal material cannot be directly correlated with the distribution of living specimens except on a general semi-regional basis. Therefore, in an attempt to make a meaningful statement as to the direction and magnitude of transport, a consideration of the hydrodynamic regime in these waters was undertaken. Connected with this effort, a detailed analysis of sediment grain-size statistics and their distribution was performed in the hope that this would shed some light on the probable effect of wave and current energy at the sea floor and provide a basis for discussion of biota-substrate relationships.

A complication is introduced by the complex Pleistocene and Holocene history of the area involving repeated emergence and submergence. Care must be exercised to separate skeletal material derived from the existing community from fossil remains admixed during the Holocene transgression. An understanding of the geologic history and associated biofacies is therefore important and has received considerable attention.

Samples and observational data were obtained through the use of SCUBA. Collection of living specimens and evaluation of biogenic material were confined primarily to those species which 1) contribute significant skeletal debris or 2) are active in bioturbation of the sediments. A quantitative approach was adopted wherever practicable.

Sample material was evaluated statistically and parameters of paleoecologic significance, outlined by Fagerstrom (1964), were calculated and considered in terms of their applicability to the geologic record.

REGIONAL SETTING

Geology

The study area is situated off the Florida coast of the Gulf Coastal Lowland (Vernon and Puri, 1964), a physiographic subdivision of the Gulf Coastal Plain which encircles the Gulf of Mexico. The underlying formations of Cretaceous and Tertiary age dip southwestward into the Gulf Coast Geosyncline and the Mississippi Embayment. The younger Tertiary sediments are beveled and overlapped in the subsurface by Quaternary alluvial and marine sands which are exposed along the coast and control the present topography of the Coastal Lowland.

The distribution of Upper Tertiary and Quaternary sediments is of interest, because during periods of lowered Pleistocene sea level these strata were exposed to subaerial erosion on the continental shelf and now exist as submerged outcrops. Tanner (1969) and Vause (1969) report outcrops of Early Miocene (Tampa?) limestone in 100 feet of water off the coast near Panama City. However, in the area of research, subsurface data indicate that only post-Miocene sediments are sufficiently shallow to be possible contributors to present bottom sediments and topography (Figure 4).

Fine- to coarse-grained sediments of the Citronelle formation of probable Early Pleistocene age (Marsh, 1966) rest unconformably on an irregular surface of truncated Miocene Tampa Limestone, Pensacola Clay, and coarse clastic sediments in the subsurface of the Florida panhandle. Progressively older Miocene strata are overlapped to the north and east reflecting the general southwest dip of these sediments. In the research area the Citronelle is reported to rest on the lower member of the

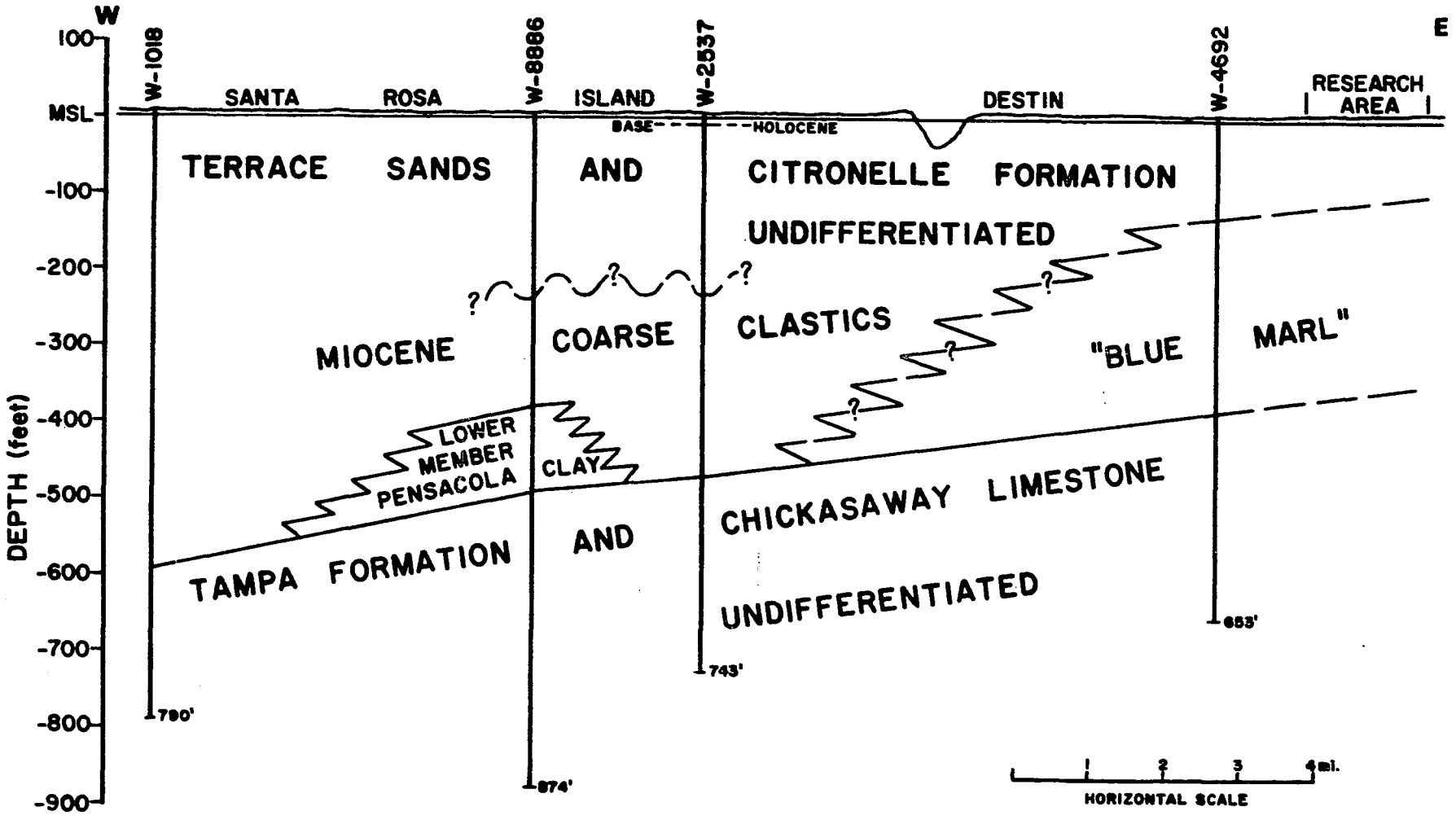


Figure 4. Shallow Stratigraphy in East-West Cross-section Through Moreno Point and Santa Rosa Island. Inferred from Marsh (1966) and Water Well Records.

Pensacola Clay (Marsh, 1966), but well data indicate a thick section of undifferentiated Upper Miocene clastics and Quaternary sands above the top of the Tampa Limestone (Foster and Pascale, 1971). The top of the Tampa, occurring at about -500 feet, seems to be the only definite datum in the shallow subsurface.

Although the Citronelle is entirely unfossiliferous to the north, marine fossils occur in outcrops and wells near the present coast. Bivalve species recovered from wells are now commonly found living in nearshore Gulf waters. These species are quite distinct from those found in the marine Miocene coarse clastics. The Citronelle is interpreted to consist of alluvial sands and gravels to the north interfingering with equivalent marine sands to the south.

Several seaward sloping terrace surfaces have been identified in peninsular and panhandle Florida which are coextensive with surfaces found in adjacent coastal regions. The surfaces represent the inland extension of the Gulf of Mexico continental shelf during periods of high sea level stand. The age of the terraces is uncertain. Only the youngest and lowest terrace (the Pamlico surface), whose shoreline is found inland at elevations of 25 to 30 feet, is of undoubted Pleistocene age. Alt and Brooks (1965) refer higher (and therefore older) terrace surfaces to the Plio-Pleistocene and Late Miocene. They contend that the Pamlico surface is underlain by multiple marine beds separated by unconformities and that the 25 to 30 foot shoreline marks the predominant Pleistocene interglacial sea level stand. However, Marsh (1966) and others (MacNeil, 1950; Vernon, 1942) regard all terraces as having originated during successive interglacial periods. For example, the Penholoway terrace with a shoreline at 70 to 80 feet is referred by Marsh to the Sangamon

interglacial with an age of 75,000 to 90,000 years BP, and the Pamlico terrace to a mid-Wisconsin transgression at 35,000 BP. The fine to coarse marine sands deposited on these terrace surfaces are thin and virtually indistinguishable from the underlying Citronelle.

At some point these surfaces must merge with the present surface of the subaqueous continental shelf or lie buried beneath it. Maximum nearshore radiocarbon dates of about 35,000 BP (Hyne and Goodell, 1967; Shumway et al.,1961) suggest that only the Pamlico terrace is exposed on the seafloor of the inner continental shelf. This does not preclude the possibility of the presence of older Pleistocene deposits especially in light of the Miocene exposure mentioned previously.

General Sediment Distribution

The axis of the Desoto Canyon, which lies southwest of the study area, marks the boundary between the two major petrographic provinces of the eastern Gulf; 1) the carbonate Florida Platform to the east and 2) the clastic province to the west. The Florida Escarpment, which is formed by the basinward edge of flat-lying Lower Cretaceous limestones, is the western edge of the Florida Platform and continental shelf (Antoine and Gilmore, 1970). West of the Desoto Canyon the Escarpment is buried beneath the clastic wedge of the Mississippi Embayment. The study area is located on the westernmost extension of the Florida Platform.

General sediment surveys by Lynch (1954) and Ludwick (1964) have shown that both clastic and carbonate sediments are exposed on the continental shelf of the Florida Platform. Sediment profiles (Ludwick, 1964) from the coast of the Florida panhandle to the 600-foot isobath

indicate an inner Cape San Blas sand facies and an outer Western Florida lime mud facies. The Cape San Blas sand facies parallels the panhandle coast and presumably extends southward along the peninsular coast, although this area was not studied by Ludwick. The boundary between the lime mud facies and nearshore sand facies is transitional between 25 to 40 miles off the coast of Moreno Point and in 150 to 300 feet of water. In other areas an abrupt change in slope marks a sharp boundary between the two facies.

West of the study area the Mississippi-Alabama sand facies of Ludwick (1964) interfingers with the coarser sands of the Cape San Blas facies. South of the Mississippi-Alabama sand body lies another area of high lime content, the Outer Shelf lime, which is probably coextensive with the Western Florida lime mud but differs in having a higher percentage of quartz sand and coarser grains.

Thus, the area of research lies on the inner margin of the Cape San Blas sand deposit. The specific sediment types developed within that general facies will be discussed in connection with the present investigation of sediments in the research area.

Holocene History

The Holocene history of the research area and the adjacent continental shelf concerns eustatic sea level rise and transgression across the Pleistocene land surface. Ballard and Uchupi (1970) and Ludwick and Walton (1957) have identified topographic features of the present submerged shelf of the Gulf of Mexico which they interpreted as relict features of the Holocene sea level rise. These include ancient strandlines, drowned coral and *Lithothamnion* pinnacles near the present edge

of the continental shelf (see also Lynch, 1954) and submerged barrier island-spit-lagoon complexes.

Hyne and Goodell (1967) described a system of parallel troughs and ridges which trend southeast at 70° to the present coast on the inner continental shelf off Choctawhatchee Bay. They attributed this topography to subareal dissection of the exposed shelf during Late Pleistocene lowered sea level. Superimposed on this supposed alluvial valley system Hyne and Goodell found two linear sand bodies in 70 and 90 feet of water respectively which trend at roughly 30° to the present coast 5 miles south of the research area and appear to intersect the coast 8 miles to the east. The geometry and texture of these sand bodies suggested an origin as barrier islands and spits, analogous to St. George Island and St. Joseph Spit located on the western margin of the modern Apalachicola Delta. Subsequent to their formation, the supply of sand provided by longshore drift was unable to keep pace with the rapid rise in sea level, and the barrier islands became submerged and modified by shoaling waves and currents. In the interpretation of Hyne and Goodell, sands from the submerged barriers were washed landward over the relict topography and lagoonal deposits in explanation of the fact that only in one case were shallow water and bay macrofossils recovered adjacent to these features. Radiocarbon dates on shell material recovered from the surface of the -70 foot sand body suggest that submergence occurred about 5,000 years ago. These barrier islands may be part of the system of bays, barrier islands, and lagoons reported by Ballard and Uchupi (1970) to occur at a depth of 32 meters (7,000 years BP) near Mobile Bay and Cape San Blas.

The research area is landward of the -32 meter coastal complex. This general nearshore zone consists of both relict and modern features

(Ballard and Uchupi, 1970). The discovery by Shumway (1961) of a submerged forest in 18 meters of water off Panama City, 35,700 to 36,500 years in age, suggests that much of the present inner shelf topography may be relict. On the other hand, Hyne and Goodell (1967) attributed the asymmetrical profile and sedimentary character of the troughs and ridges to post-Pleistocene or modern marine processes.

In summary, the study area was exposed to subareal conditions including erosion and alluvial sedimentation until about 9,000 years ago based on published curves of sea level rise (see Milliman and Emery, 1968, and Curry, 1960). At that time, the barrier islands reported by Hyne and Goodell (1967) and Ballard and Uchupi (1970) were forming and enclosed lagoons or bays on their landward side. The research area became part of the bay-lagoon complex until 5,000 years ago when the barrier island was drowned and the area assumed the character of an open Gulf coast.

GENERAL PROCEDURES

Three lines of traverse were established normal to the coast along which sampling of sediment and biota proceeded (Figure 5). Sample locations were plotted on an aerial photomosaic from sextant sightings on prominent coastal features. Lines L1 and L2 were located to investigate the general distribution of sediments and biota on the offshore sand plain and shoreface. Line L1 intersects the area of limestone outcrop mentioned previously and was designed to test for coastward transport of epifaunal biogenic material derived from that substrate. However, it became apparent during the processing of line L1 samples that the distance between sample locations near the limestone was too great to assess the degree of such transport. Therefore, line RL1 (Figure 6) was established across the area of outcrop and extending about 120 feet onto the sand plain in both a coastward and seaward direction to provide a detailed determination of the contribution of the limestone epifauna to the surrounding sediments.

Corresponding sample locations on lines L1 and L2 are equidistant from the coast. Ten such locations, about 500 feet apart, were occupied on both lines. At each location four samples of biogenic material and two sediment samples were collected with SCUBA. In addition, samples of the living biota were obtained and a photographic record of communities and sedimentologic features was made. Four supplementary sediment samples were collected at the coastward end of the line L2 in 35 feet and 25 feet of water and on the bar crest (BC) and trough (T) to complete the investigation of nearshore sediment distribution trends.

Line RL1 (Figure 6) consisted of a nylon line stretched along the

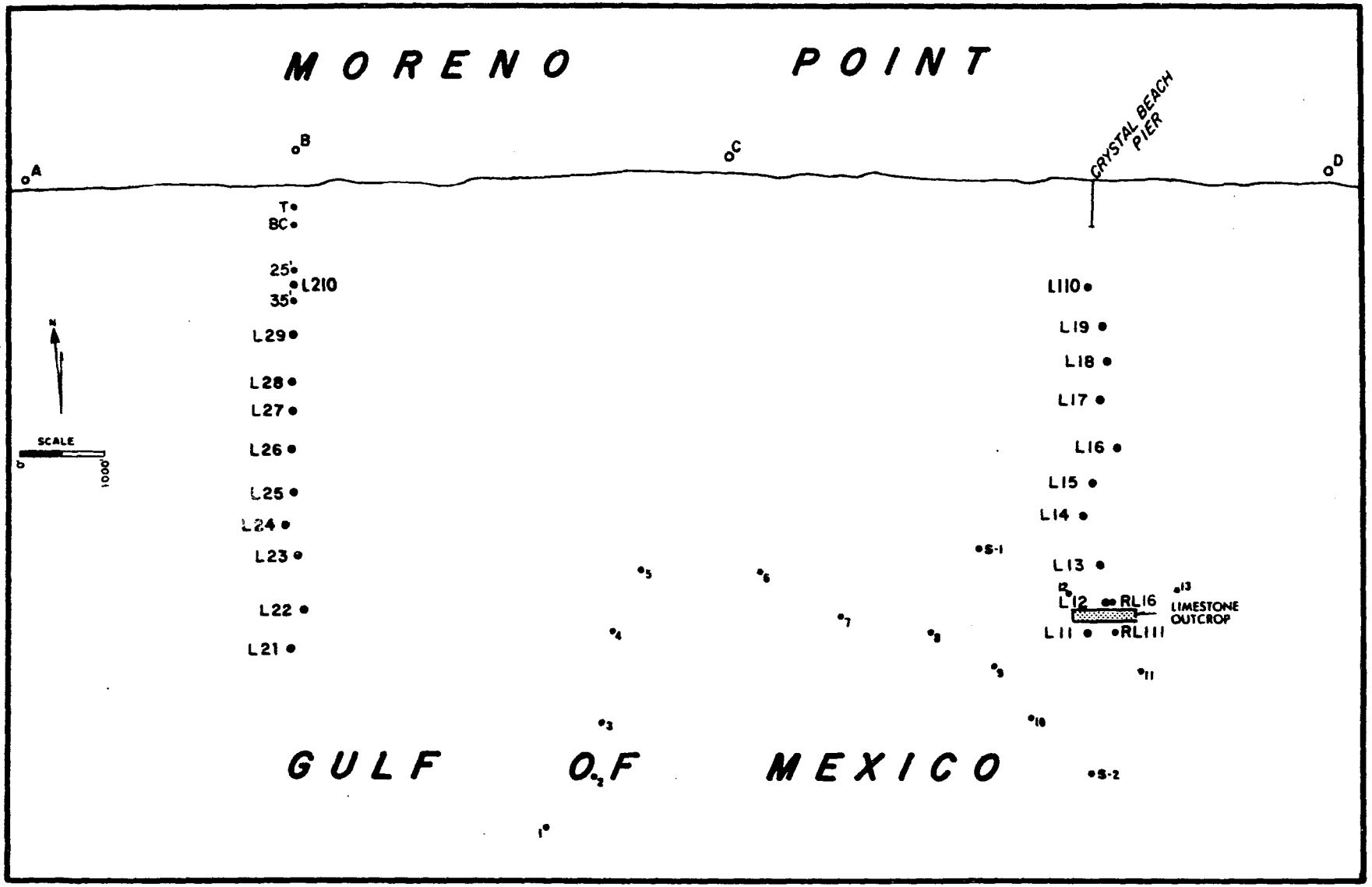
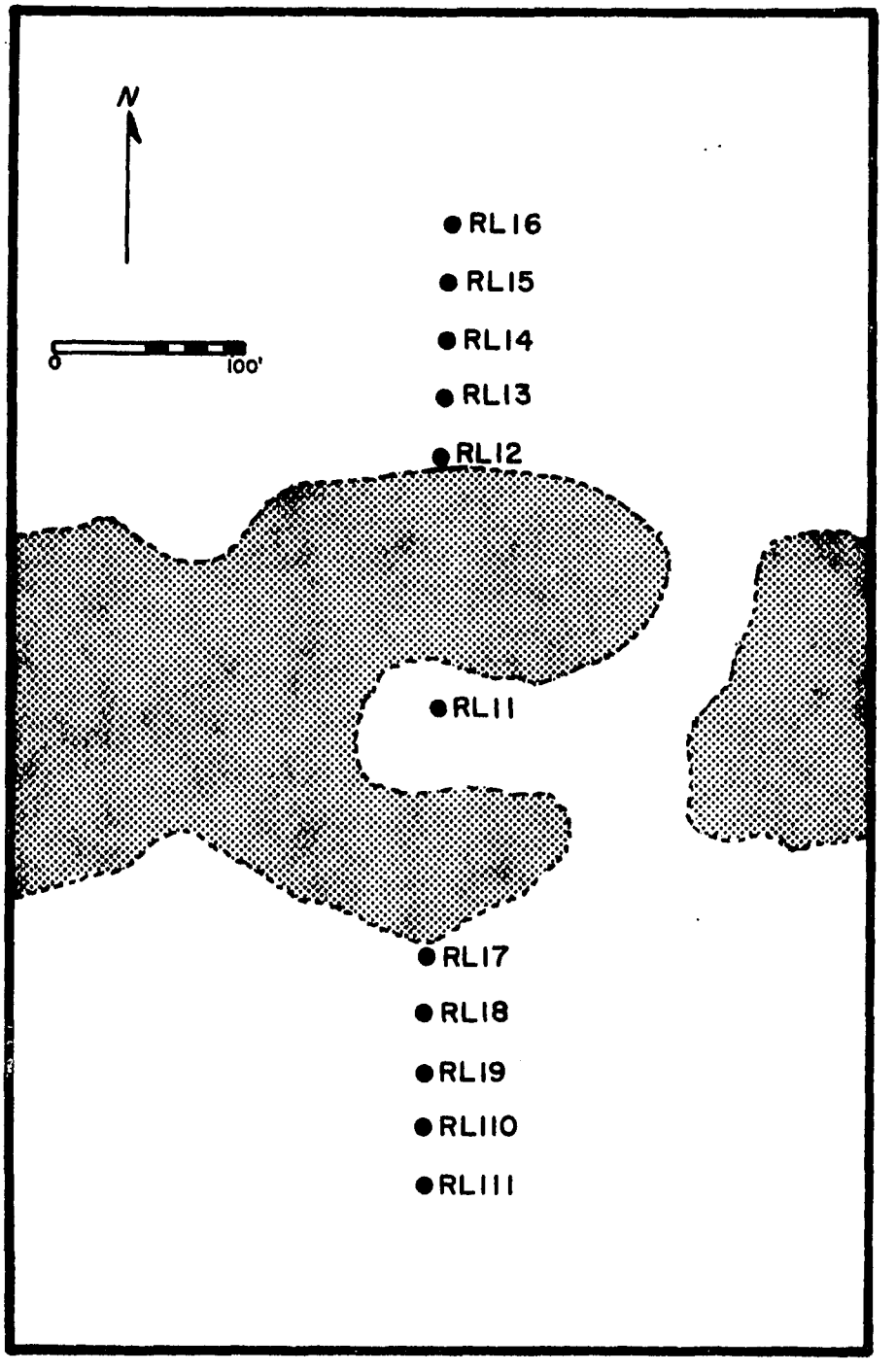


Figure 5. Sample Locations and Observation Points

Figure 6



Sample Locations on Line RL1. Configuration of outcrop area (stippled) is diagrammatic in detail.

bottom across the center of the limestone outcrop in a north-south direction (normal to the coast). Two samples of biogenic material were collected at each of five locations along the line to the north and south of the outcrop. One sample pair was obtained from a pocket of sediment within the rock area (RL11). The interval between locations on the sand plain to the north and south was about 30 feet, with the first location on both sides being immediately adjacent to the rock. The nylon line was relocated each working day by a system of beach ranges sighted by eye, since boating activity precluded the use of buoys. This method proved to be extremely accurate and the line was always located with ease in conjunction with an underwater compass (see Appendix A).

Considerable time and effort were expended in the investigation of the area of outcrop and the surrounding sediments not only because of the diverse community found on the rock itself but also because the surrounding sediments appeared, from preliminary field observations, to reflect strongly the effect of the Holocene sea level rise. The coarse-grained nature of the sediments and the preservation and species composition of the associated biogenic material suggested that these accumulated under conditions which do not now exist. An understanding of processes responsible for the character of the thanatocoenosis must therefore include an understanding of the detailed history of the area. In an attempt to accomplish this objective, many dives were made in this area in addition to those specifically to make sample collections. It may be appropriate here to mention that low underwater visibility was the chief hinderance in the investigation of the area. Each dive constituted an isolated observation; enough observations were made to provide an overall concept of distributional relationships.

Samples of biogenic material collected at the above-mentioned locations were found to be too small to contain a representative sample of the living macro-invertebrates. Therefore, a census of benthic biota was made in a 100-square-foot area of the seafloor on lines L1 and L2 at alternate locations.

Supplementary dives were made at locations 1-13 indicated on the map (Figure 5) which yielded information on water depth, sediment type, sedimentary structures, community composition and distribution, and other bottom characteristics. At locations S-1 and S-2 two sediment samples were obtained to further define distribution patterns in the outcrop area. Many other dives, both in the research area and at other locations on the adjacent shelf, contributed to an understanding of the distribution of biota and sediment types.

SEDIMENTS

Previous Work

One of the earlier descriptions of the marine sediments of the Florida panhandle was that of Lynch (1954). He described the shelf east of Pensacola as consisting of a narrow coastal belt of quartz sand followed offshore by biogenic carbonate sediments. Lowman (1951) subdivided the shelf sediments south of Pensacola into two provinces: 1) white fossiliferous beach sands extending to depths of 20 fathoms, and 2) areas of coarse sediment and calcareous banks consisting of algae, coral, Bryozoa, bivalves, and Foraminifera found at 20 to 40 fathoms.

A more detailed study of the marine sediments of the northeastern Gulf was conducted by Ludwick (1964). Two sampling profiles, normal to the coast, were made on the panhandle shelf one of which fortuitously passed near the present research area. From the shoreline to a distance of four nautical miles (70-foot water depth) the sediments consist entirely of sand-size material. From four miles to a distance of 35 miles (-230 feet) patches of silty sand appear. Beyond 35 miles the sediment rapidly becomes finer with grains less than .062mm in diameter predominating. The median diameter fluctuates erratically from the coast to a distance of 35 miles, beyond which no data were obtained. Sediments found at distances of 20 to 35 miles (-150 to -230 feet) appear to be generally coarser than those nearer the coast although the diameter of the coarsest grain decreases with distance from shore. The percent $CaCO_3$ increases erratically from a low of less than one percent at the coast to almost 100 percent at a distance of 17 miles (120 feet). Ludwick recognized three distinct subfacies of the shelf sands: 1) fine-grained,

whitish-gray, well-sorted quartz sand, 2) medium-grained, gray, moderately well-sorted quartz sand containing some large quartz and quartzite grains 1 to 2mm in diameter, and 3) coarse-grained, yellow-brown, iron-stained quartz sand containing up to 25 percent quartz and quartzite grains coarser than 1mm and some quartz grains 1.5 to 2.5mm in diameter. The fluctuation of median grain size is attributable to alternating bands of subfacies 1 and 2 to a distance of 17 miles from shore (-120 feet) with admixture of subfacies 3 at greater distances.

Hyne and Goodell (1967) investigated the sediments of the inner continental shelf off Moreno Point in terms of their relationship to the Holocene sea level rise (see Holocene History). They found that sands of elevations are generally coarser than sands of adjacent lows, but that the sand surface is often mantled with thin (1mm to 3cm) layers of silt and clay at distances greater than five miles from shore.

Tanner (1959), Kofoed and Gorsline (1963), and Vause (1959) studied the nearshore and coastal sediments in the vicinity of the delta of the Apalachicola River. Tanner described three predominant sediment types in water of 100 feet or less: 1) wave-cut karsted limestone in deeper water, 2) shell hash, 3) quartz sand. He found that shell hash increases in abundance seaward from the coast. The mean grain-size also increases seaward from .2 to .3mm at the beach to .6mm offshore accompanied by a decrease in sorting. At variance with Hyne and Goodell (1967), Tanner reported that sediments are coarser in depressions and finer on ridges. He concluded that quartz sand and shell hash form a thin veneer over the underlying limestone of Miocene(?) age.

The findings of Vause (1959) and Kofoed and Gorsline (1963) were in general agreement with Tanner (1959). Vause also stated that the

sands coarsen continuously seaward from the coast and that their sorting decreases, a reflection of the increase in mean grain size. He described coarse-grained sediments with rock fragments and large shells near limestone (Tampa?) outcrops. Samples of the limestone contained from 61 to 90 percent $CaCO_3$ with the balance consisting of angular, coarse quartz sand grains. The character of the sediment surrounding the limestone outcrops suggested its derivation from erosion of that rock. Vause also noted a general increase in $CaCO_3$ content with distance from shore. He regarded the coarser offshore sands as a lag deposit from Pleistocene alluvium. Kofoed and Gorsline (1963) described marine sediments in the Gulf of Mexico off Apalachicola Bay. In 70 feet of water the sediments consist of coarse sand with 10 to 20 percent shell material and limestone fragments. They found patches of sand with greater than 40 percent carbonate at 65 feet but noted a general decrease in calcium carbonate content shoreward. They concluded that the coarse quartz sands offshore are relict from alluvial deposits of the Apalachicola River deposited during periods of increased gradient and lowered sea level and that the coarse shell material is indigenous. The fine coastal sands were thought to be derived from the present River. The high calcium carbonate content of the deeper water sands reflects the low influx of terrigenous sediments.

The grain size distribution and origin of biogenic carbonate in the marine sediments of the West Florida shelf was the subject of an investigation by Force (1969). As found by others for the panhandle coast, he noted a seaward increase in calcium carbonate content. He also demonstrated that the median grain size of the terrigenous fraction is slightly smaller than that of the associated carbonate due to the non-

sphericity of the biogenic grains and concluded that grain size frequency distributions of both components arise from the same processes of sorting in the marine environment.

Methods

Sediment samples were collected by pressing wide-mouthed jars into the sediment. This procedure minimized the washing out of fines during collection. Blocks of the limestone were obtained for examination and analysis. Several subsurface samples of unusual sediment type were also collected which were thought to be of interest in terms of past depositional environments.

Samples from lines L1 and L2 were estimated to contain less than one percent silt and clay. Analyses of those fines were therefore not undertaken. The bulk samples were washed over a 4.00 ϕ (.062mm) screen to remove fines and soluble salts, and then dried and weighed. Each dried sample was passed through a -0.50 ϕ (1.41mm) sieve and the larger grains removed for later analysis. The size fraction between -0.50 ϕ and 4.0 ϕ was split into 70 to 100 gram subsamples. One subsample from each sample was sieved on a Ro-Tap through 18 screens arranged at .25 ϕ intervals from -0.25 ϕ (1.19mm) to 4.00 ϕ (.062mm). The resultant weights of the grain-size classes were then tabulated.

The fraction of total sample coarser than -0.50 ϕ (1.41mm) was sieved by hand through five screens at .25 ϕ intervals from -1.50 ϕ (2.79mm) to -0.50 ϕ (1.41mm) but including also three screens of -1.75 ϕ (3.36mm), -3.00 ϕ (7.92mm), and 15.85mm for the largest grain sizes. The weights of these grain-size classes were corrected for the split weight of the finer fraction and were then tabulated. The tabulated

weights of all grain-size classes were punched on computer cards and subsequently analyzed using the Textural Analysis Program (Texan) developed by Adams (1967). Output consisted of the commonly used measures of central tendency, dispersion, skewness, and kirtosis (e.g., moment measures, Folk's statistics, Inman's statistics), a frequency table, and graphs of frequency distribution, cumulative frequency, and cumulative frequency with probability ordinant. Statistical summaries and graphs were prepared from these data to characterize the nature of the marine sediments and to interpret their distribution.

Two subsamples of each sample were weighed and then leached with dilute HCl to remove $CaCO_3$. The residues were washed, dried, and weighed to determine the percent $CaCO_3$. One of these residues was subjected to the method of grain-size analysis described above to determine the characteristics of the quartz fraction alone.

The grain-size distribution of $CaCO_3$ in the sediment was determined by leaching each grain-size class of the bulk sediment with dilute HCl, washing, drying, and reweighing. Weights of $CaCO_3$ for each grain-size class were found by subtraction and were tabulated and analyzed with the Texan program as above.

Small samples of limestone were obtained from the center of larger blocks to avoid contamination by encrusting and boring organisms. Five of these were leached with dilute HCl to ascertain the percent $CaCO_3$. Two residues, consisting entirely of sand sized terrigenous grains, were analyzed for their textural characteristics. The mineralogy and morphology of the cement as well as constituent grains were studied in thin section and also with the JOELCO JSM-2 scanning electron microscope. A quantitative determination of cement composition was undertaken by

infra-red spectrophotometric methods and with the electron microprobe.

Three samples of biogenic material were age dated with radiocarbon techniques to provide additional control on the geologic history of the area: 1) *Chione cancellata* shells, 2) *Dichocoenia* sp. cuttings, and 3) lignitized wood fragments. *Chione cancellata* shells were recovered from sediment to the south of the limestone outcrop. *Dichocoenia* sp., a scleractinian hermatypic coral, was found closely associated with limestone rubble. Internal inclusions of calcite cemented quartz sand within the coral head suggest that it was derived as a fossil from the limestone. Wood fragments were collected from subsurface muddy sands south of the outcrop.

Results

In general, the marine sediments in the study area can be described as moderately well sorted, fine- to coarse-grained sands (Folk, 1968). The sands are composed of two major components, 1) terrigenous quartz sand grains, and 2) biogenic skeletal material. The biogenic component constitutes the thanatocoenosis and as such its size distribution and composition are of central interest to this study. Because shell material is a product of organic growth, its size distribution may not reflect energy levels at the site of accumulation but may merely reflect the size and productivity of shelled organisms. It is therefore more instructive to study the terrigenous and biogenic components separately than to view the sediment as a whole.

Terrigenous Component

Statistics upon which the following discussion is based represent

averages of two values derived from two random samples taken at each location. The within-location variability was found to be small for all textural statistics enhancing the reliability of established trends.

A study of the moment mean grain size of the insoluble fraction shows that the study area may be subdivided into three sedimentologic zones which parallel the coast and are thus generally correlated with depth; 1) fine sands of the upper shoreface, 2) medium sands of the lower shoreface and inner offshore sand plain, 3) coarse sands of the offshore sand plain to the limit of investigation (Figure 7). An exception to this pattern is found immediately north of the limestone outcrop area where an anomalous body of fine sand is located.

Figure 8 illustrates trends in moment mean grain size found on lines L1 and L2. The mean grain size decreases seaward along line L2 from 1.91 ϕ at the bar trough to a minimum of 2.26 ϕ at the 35 foot isobath. Although this trend was not verified on line L1, the homogeneity of the upper shoreface sands suggests that the seaward decrease in grain size is general. Offshore of the 35 foot isobath the grain size rapidly increases to the base of the shoreface at 50 feet (location 8). The mean grain size then increases slowly along line L2 to a high of 0.97 ϕ in 66 feet of water. The same trend in mean grain size is found on line L1 on the lower shoreface and inner sand plain coastward of location 5. However, on line L1 the mean grain size decreases sharply seaward to a minimum of 2.21 ϕ north of the limestone. To the south and west of the outcrop and in pockets within that area coarse sands with a mean grain size of 0.88 ϕ are found. The overall increase in mean grain size is accompanied by a seaward increase in percentage of grains of very coarse sand size and larger (Figure 9) resulting in a slightly gravelly

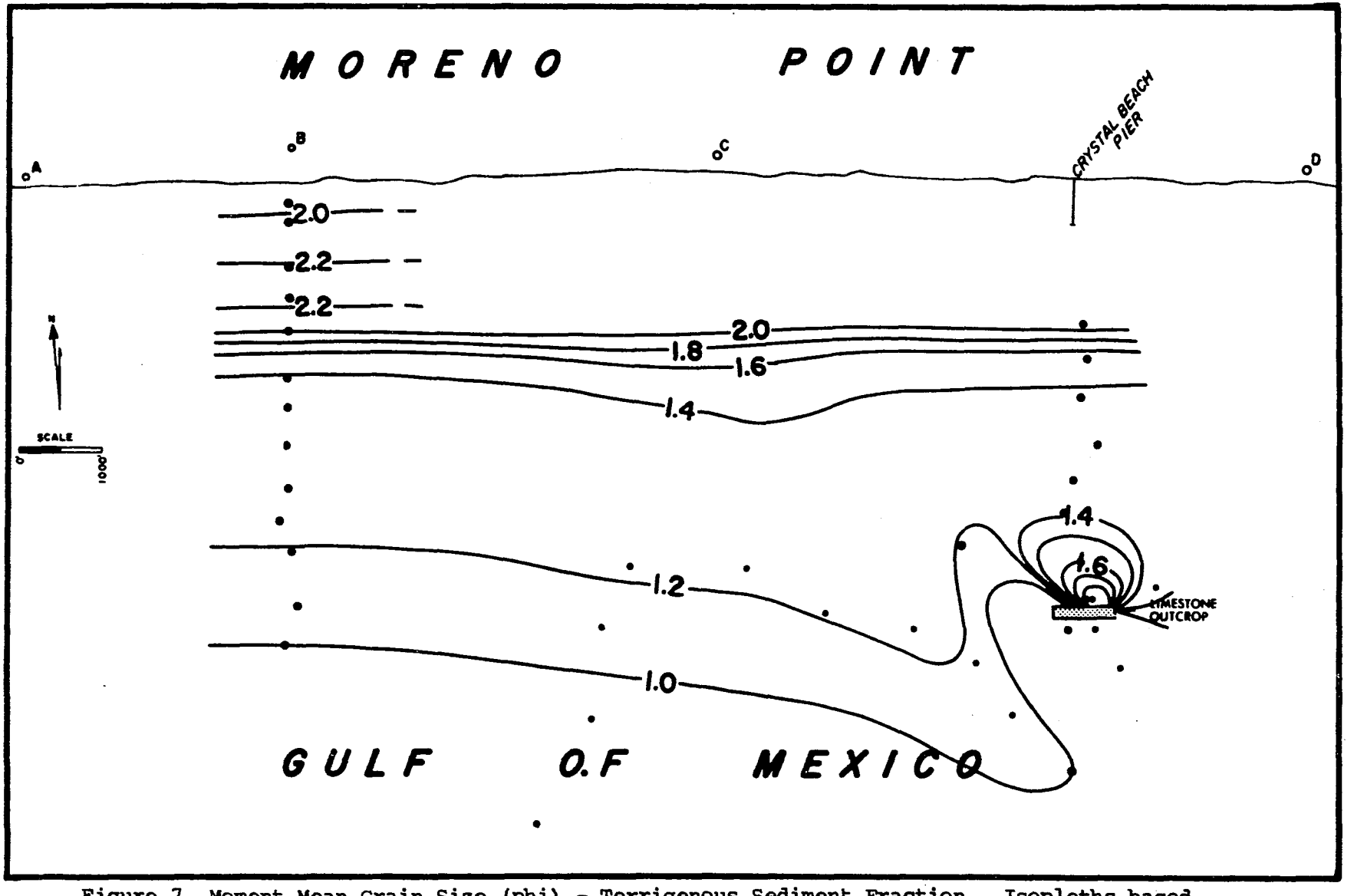


Figure 7. Moment Mean Grain Size (phi) - Terrigenous Sediment Fraction. Isopleths based on average of two measurements at sample locations (large dots).

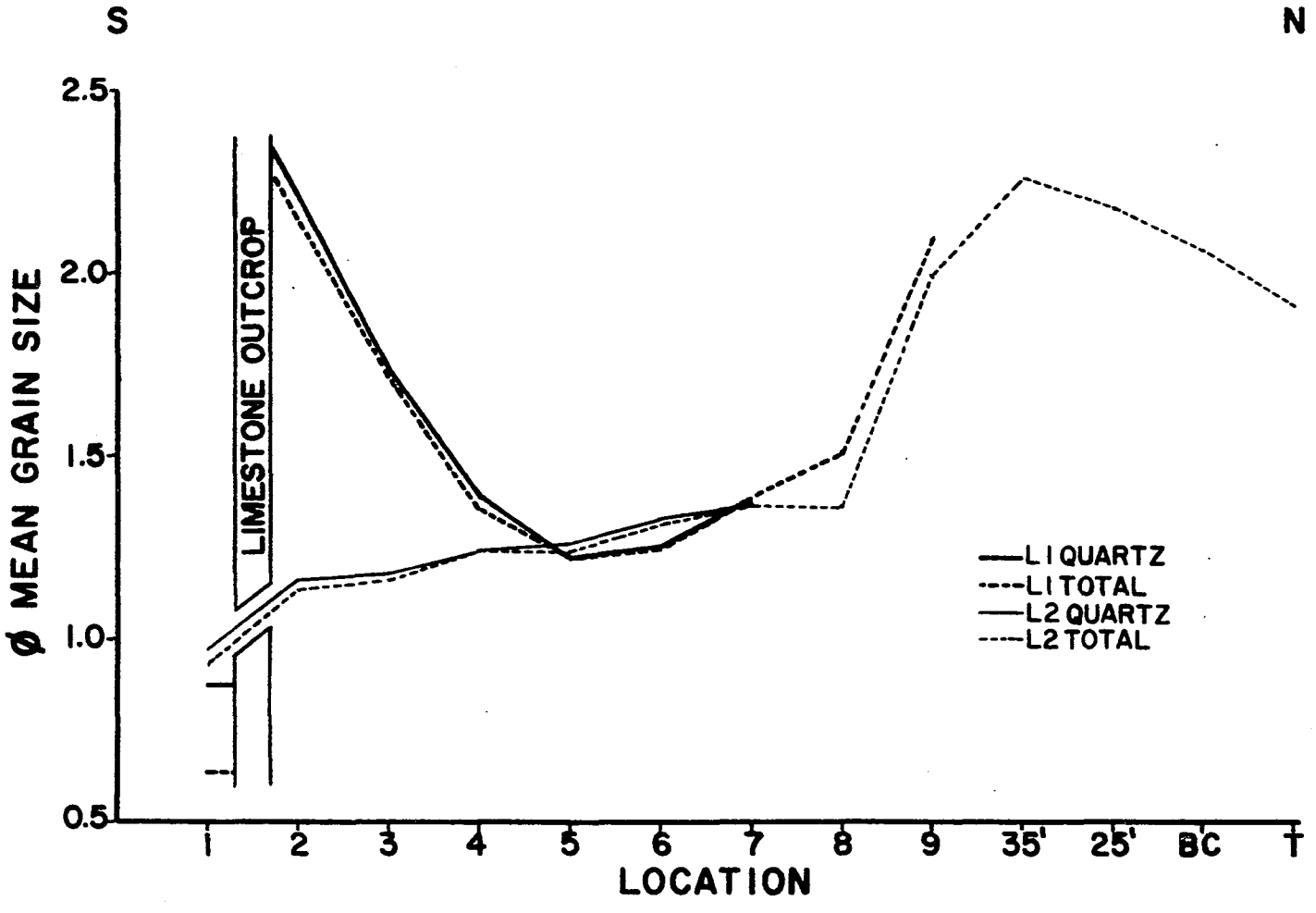


Figure 8. Trends in Moment Mean Grain Size (phi) for Terrigenous Fraction (Quartz) and Total Sediment Samples on Lines L1 and L2

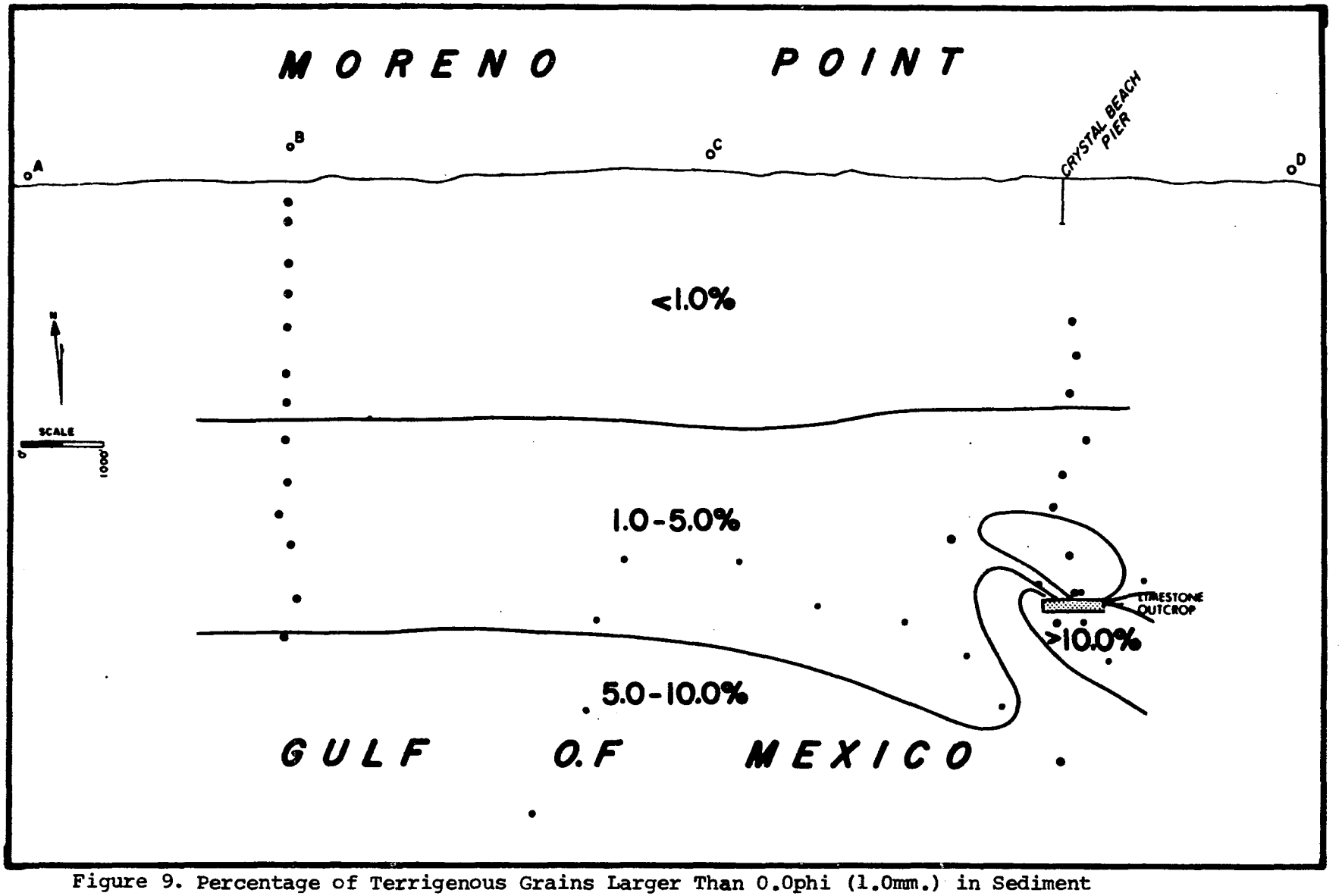


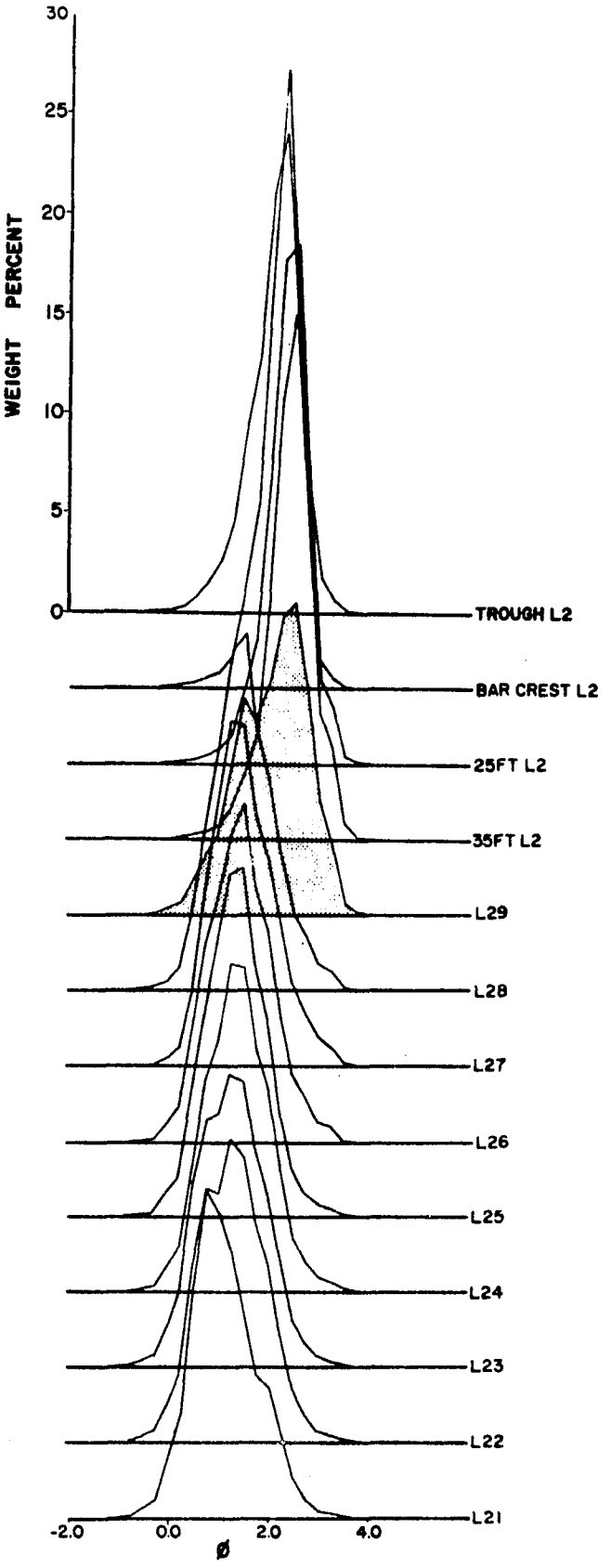
Figure 9. Percentage of Terrigenous Grains Larger Than 0.0phi (1.0mm.) in Sediment Samples. Based on average of two measurements at sample locations (large dots).

texture for the deeper sands.

The three general sediment zones are each characterized by a distinct modal grain size class or a narrow, well-defined range of modal classes (Figures 10 and 11). Modes of the fine upper shoreface sands range from 2.45 ϕ to 2.13 ϕ and coarsen coastward. A transition (well established on line L2) occurs at 45 feet (location 9) on the lower shoreface from those fine sands to the medium sands of the inner offshore sand plain. Transitional sands are bimodal with a fine mode contributed by the upper shoreface sands and a coarser mode corresponding to the modal grain size class of the medium sands. The medium sands are unimodal, and the position of the mode remains nearly constant seaward as far as the 65 foot isobath where the transition to the coarse-grained sands occurs. The coarse mode of these deeper sands can be identified as shoulders on the frequency distribution curves of adjacent shallower medium sands. These relationships are well developed on line L2 (Figure 10) but are complicated on line L1 in the vicinity of the limestone outcrop. Modal classes identical to those found on line L2 are present on the lower shoreface and innermost sand plain on line L1. But in deeper water the modes become progressively finer from location L15 to L12 (Figure 11). Shoulders are developed on the frequency distribution curves of these sands which correspond in grain size to the mode found for the coarse sands south of the outcrop (L11). The position of this mode is coincident with that determined for location L21.

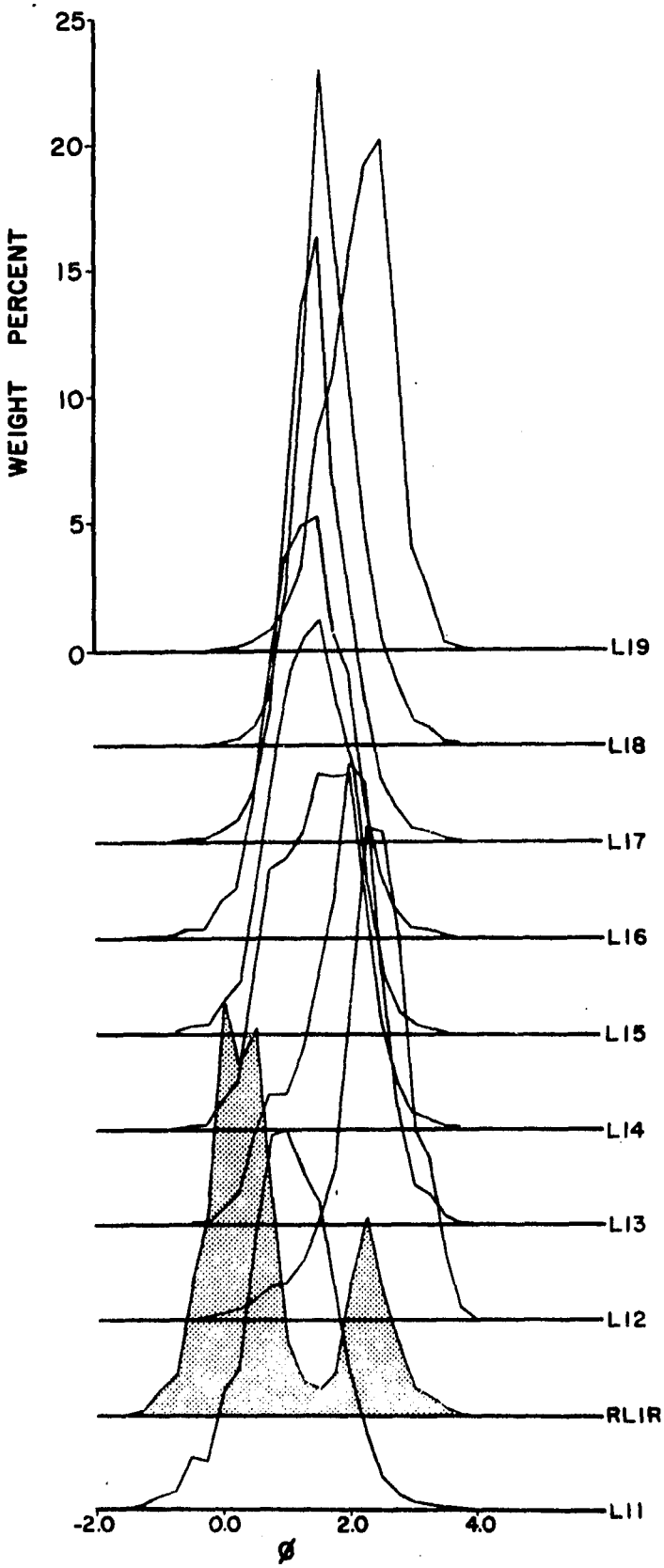
The frequency distribution for the insoluble terrigenous fraction derived from the limestone (RL1R) is included in figure 11 (stippled) for comparison. It is of interest to note at this point that the fine mode of limestone-derived sand is of the same size class as the mode

Figure 10



Terrigenous Grain Size Frequency Distribution Curves at Locations on Line L2. L29 stippled for clarity.

Figure 11



Terrigenous Grain Size Frequency Distribution Curves at Locations on Line L1. Size frequency distribution of limestone insolubles stippled.

developed in the sediment immediately north of the rock, and further that the very coarse quartz sand mode occurring in the limestone is coincident with a coarse secondary mode at location L11 south of the outcrop.

Sorting of terrigenous grains, expressed by the moment standard deviation, does not show any significant variation on the offshore sand plain or the lower shoreface. The sands do, however, exhibit better sorting on the upper shoreface on the basis of the few samples collected there. Because this trend is consistent with energy elevation in shoaling water, it is presumed real and not an artifact of sampling. When examined in terms of the Inclusive Graphic Standard Deviation of Folk (1968), the terrigenous sands of the sand plain and lower shoreface are moderately well sorted while those of the upper shoreface are well sorted.

Average moment skewness values indicate several distinct trends (Figure 12). The medium unimodal sands of the inner offshore sand plain become progressively more positively skewed from location L22 to L28. The transitional sands found at location L29 are negatively skewed reflecting the bimodal nature of the grain-size distribution. This pattern is repeated on line L1 at locations L15 to L19. The fine sands of the upper shoreface are negatively skewed reaching a minimum on the nearshore bar crest. On line L1 skewness become progressively more negative with proximity to the north side of the limestone outcrop. The coarse-grained sands found on the offshore sand plain show some variability in skewness depending on location.

Because of the uncertainty of interpretation, kurtosis will not be discussed.

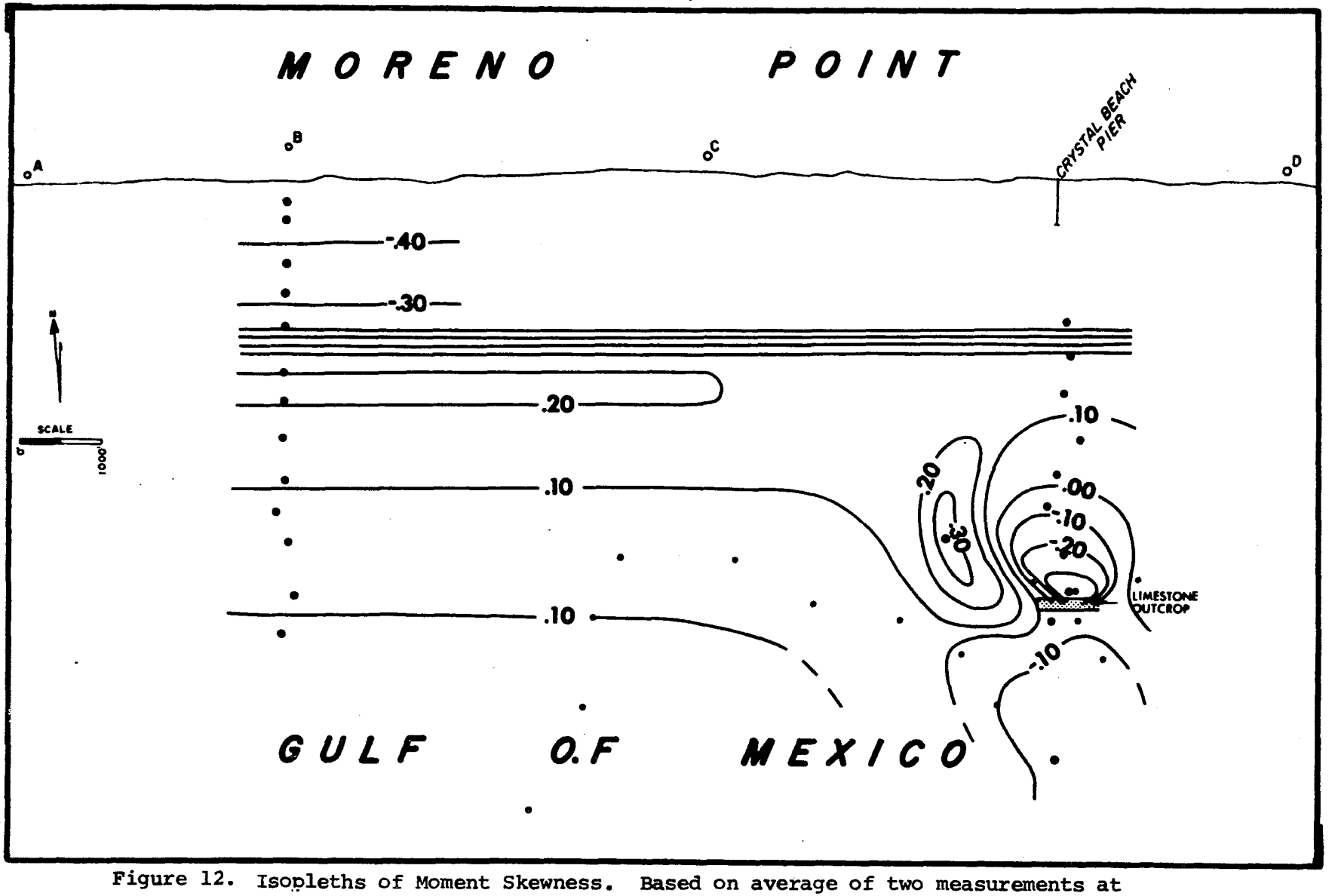


Figure 12. Isopleths of Moment Skewness. Based on average of two measurements at sample locations (large dots).

Biogenic Component

The acid-soluble fraction of these marine sediments consists almost exclusively of biogenic calcium carbonate as fragments and whole shells of mollusks, echinoids, Foraminifera, ostracods, coralline algae, and Bryozoa. The percentage of carbonate varies consistently from a low of less than one percent near the beach and on the shoreface to a maximum of 16.6 percent at location 1 on line L1 south of the limestone outcrop area (Figure 13). The carbonate percentage distribution is illustrated in map view on Figure 14. Percentages recorded represent the average of four measurements at each location, two from each sediment sample.

It is evident from a comparison of Figure 14 with bathymetry that the distribution of calcium carbonate is well correlated with depth. Isopleths of carbonate percentage are generally parallel to bathymetric contours. The relationship, however, is not linear. Calcium carbonate content increases slowly from the bar crest to a depth of 50 feet, at the base of the present shoreface, beyond which it increases rapidly to its maximum recorded value at 70 feet (Figure 15).

Biogenic calcium carbonate is not evenly distributed through all sediment grain size classes but is concentrated in characteristic size intervals. Analysis of the carbonate fraction indicates that the frequency distribution curves are strongly negatively skewed reflecting the contribution of coarse shell fragments and whole shells (Figures 16 and 17). Texturally, biogenic material can be described as strongly coarse-skewed, poorly sorted, gravelly sand (Folk, 1968). The mean grain size of the biogenic component is therefore considerably coarser than the terrigenous fraction in a given sample.

The distribution of mean grain size (Figure 18) shows trends

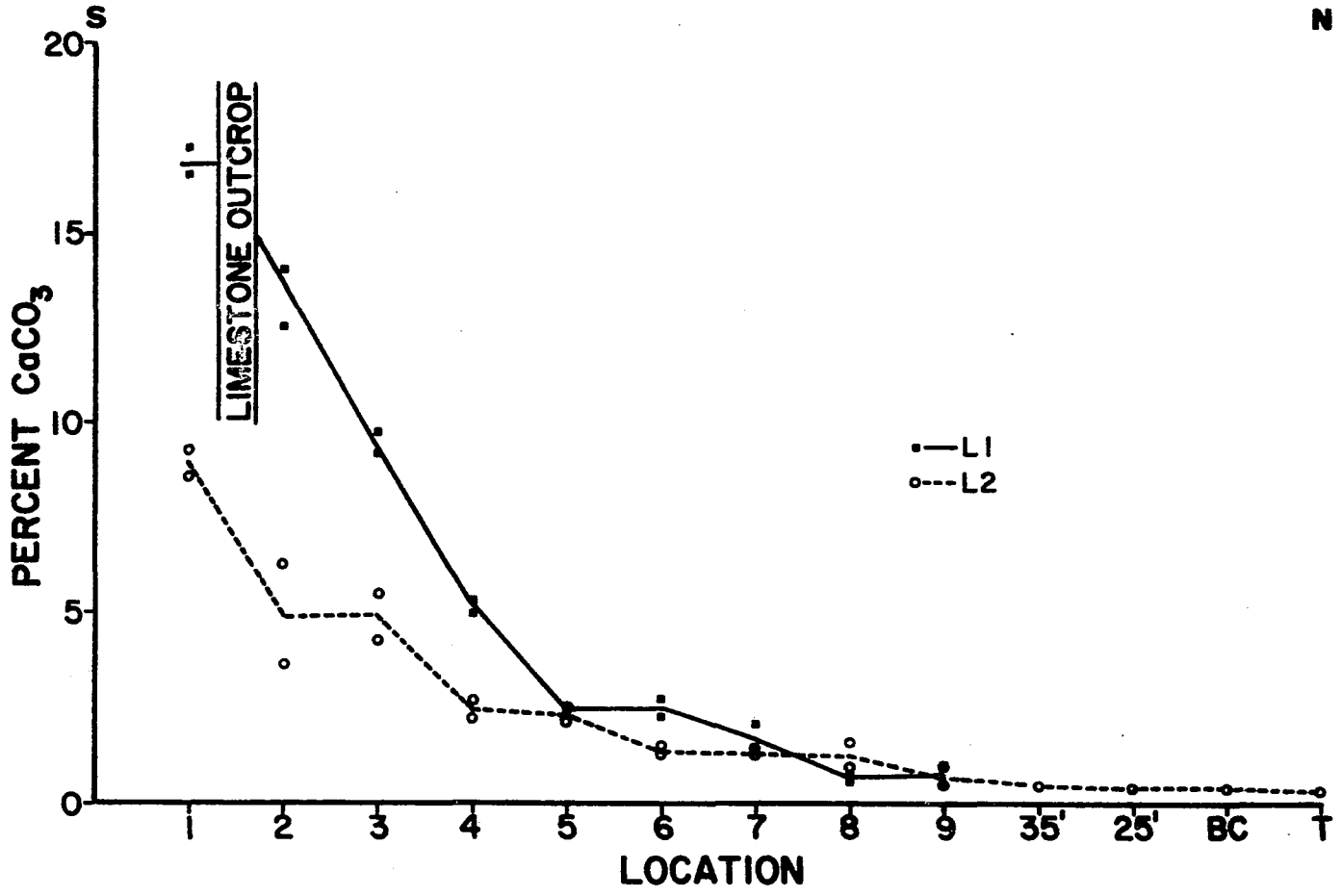


Figure 13. Percent $CaCO_3$ at Locations on Lines L1 and L2

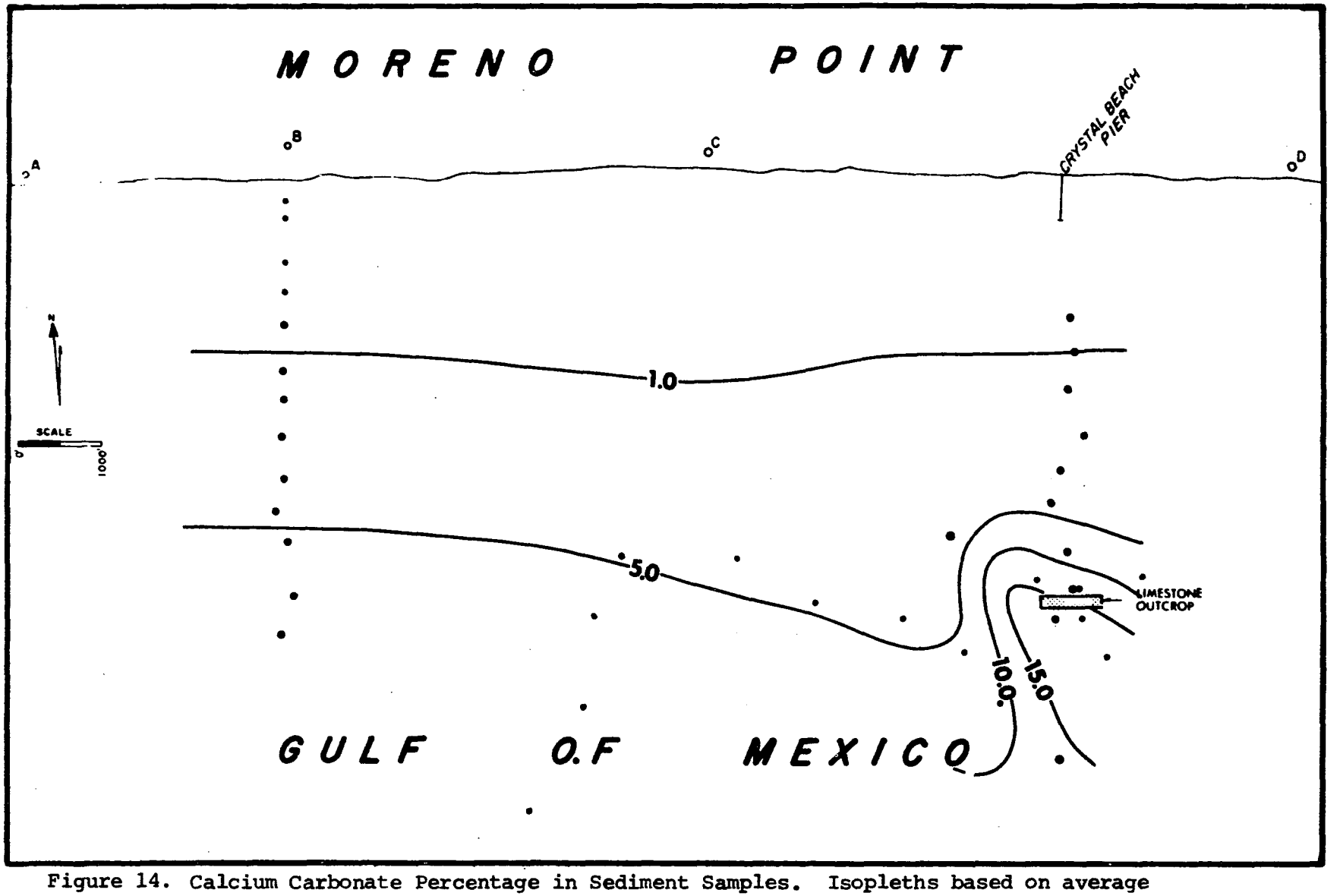


Figure 14. Calcium Carbonate Percentage in Sediment Samples. Isopleths based on average of four measurements at sample locations (large dots).

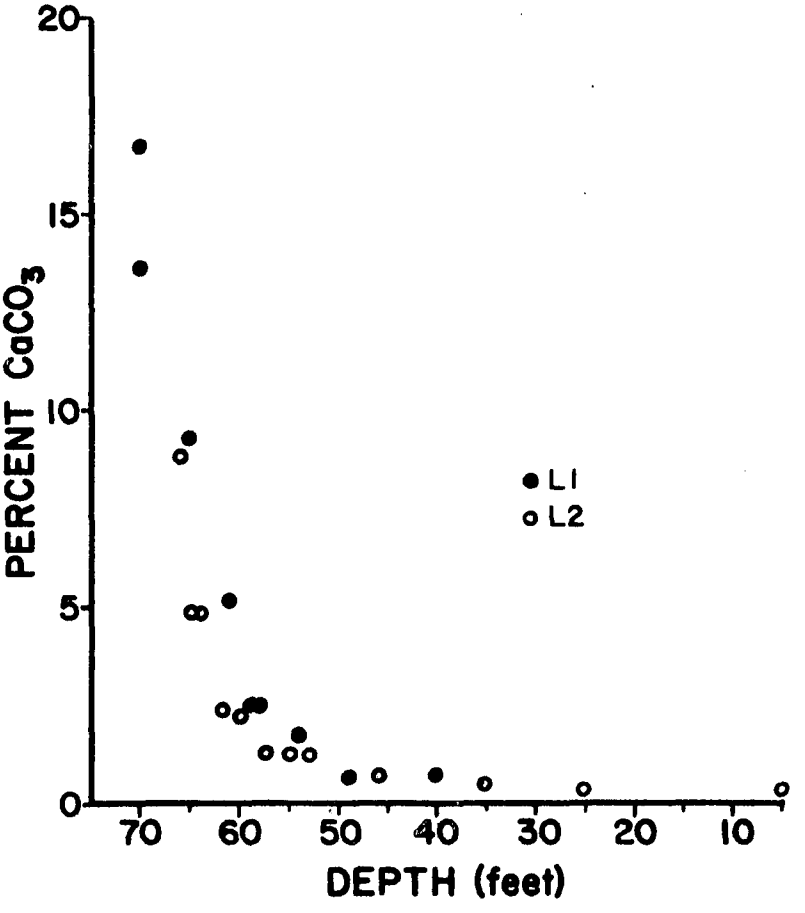
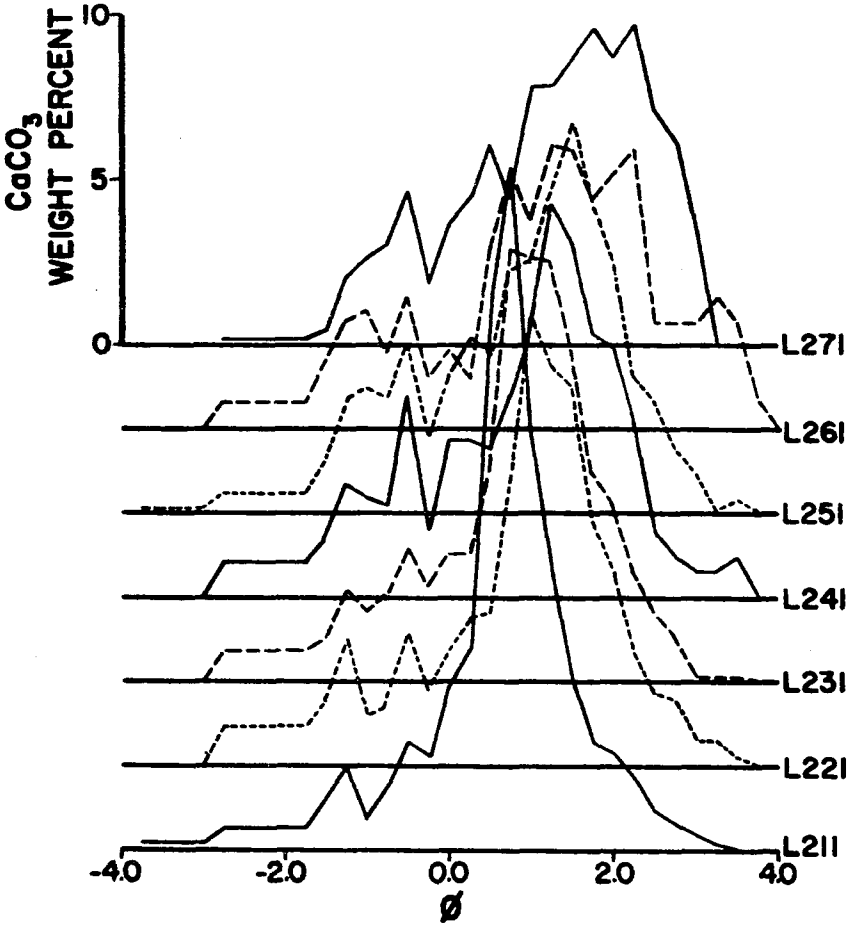


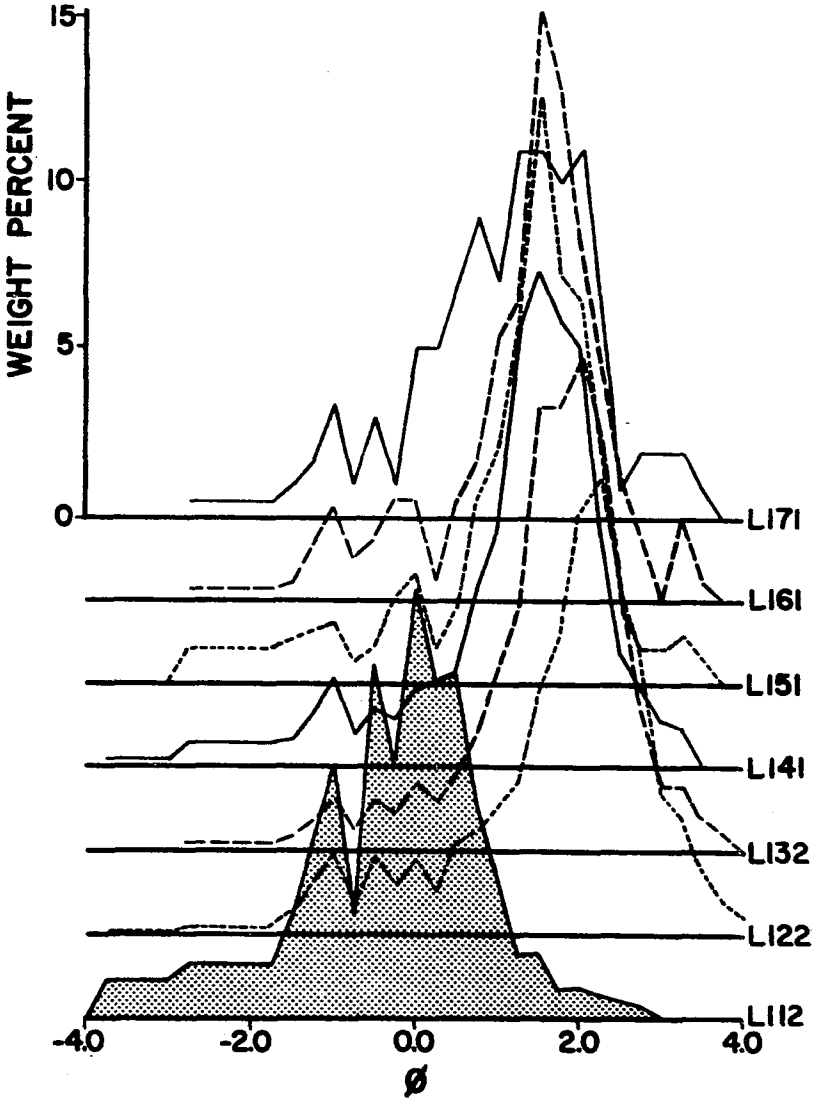
Figure 15. Relationship of $CaCO_3$ Percentage and Depth in the Research Area.

Figure 16



Size Frequency Distribution Curves of $CaCO_3$ at Locations on Line L2.

Figure 17



Size Frequency Distribution Curves of $CaCO_3$ at Locations on Line L1. Curve at location L11 is stippled for clarity.

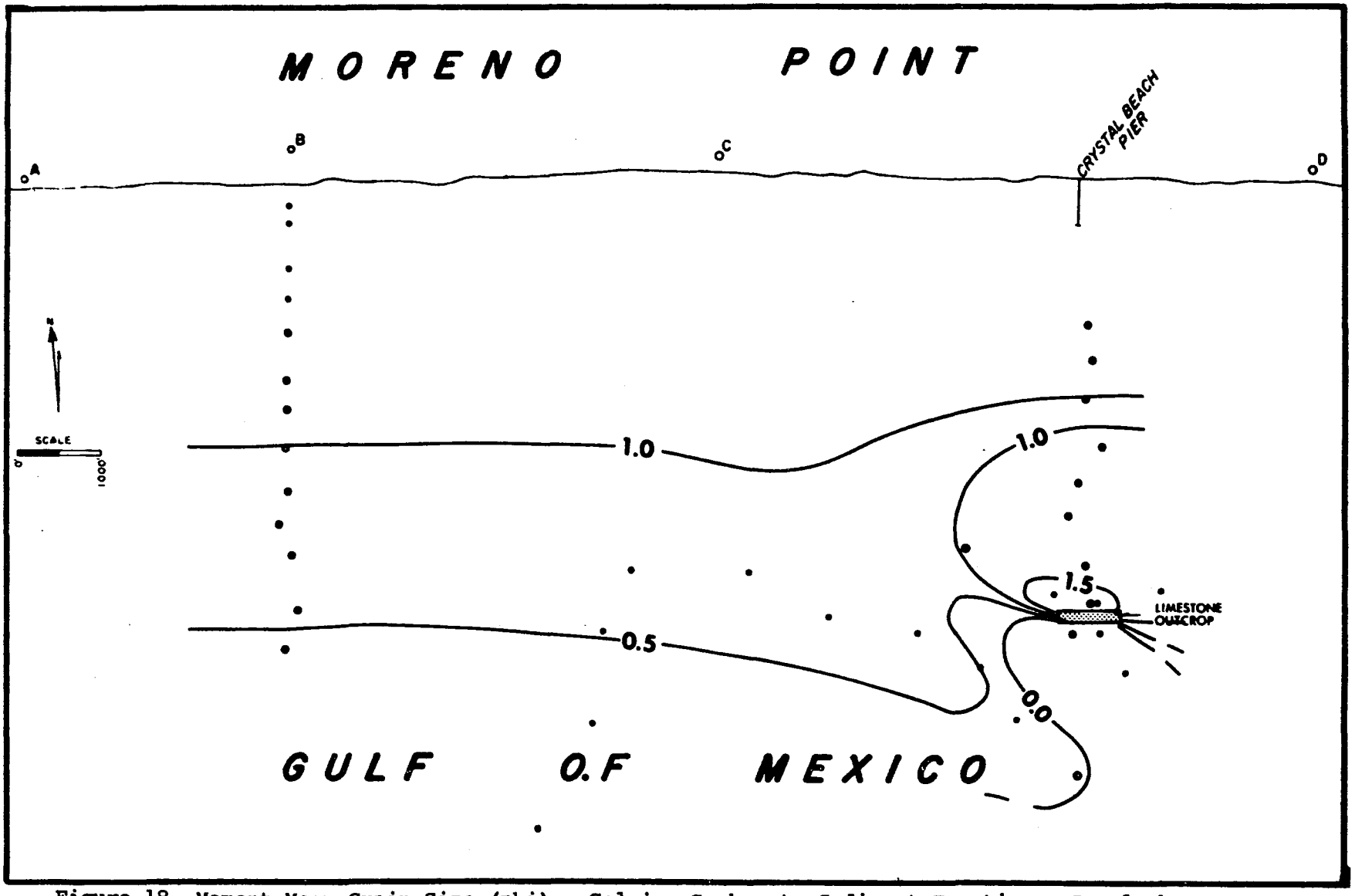


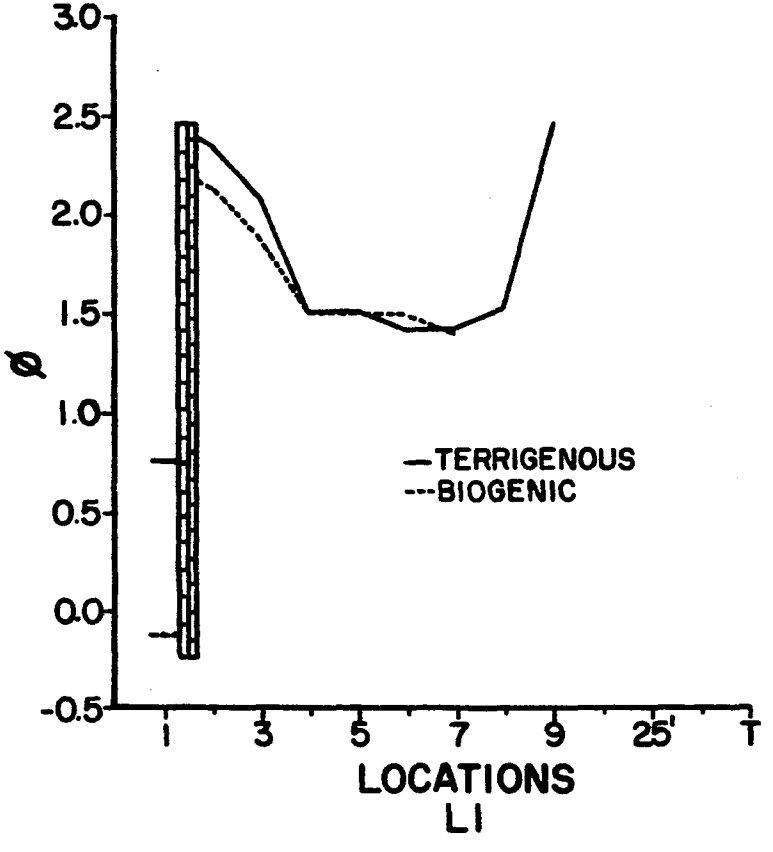
Figure 18. Moment Mean Grain Size (phi) - Calcium Carbonate Sediment Fraction. Isopleths based on one measurement at sample locations (large dots).

similar to those found for the distribution of the terrigenous component. Mean grain size increases from the lower shoreface seaward to the limit of investigation. Sediment samples from locations shallower than 50 feet were not analyzed in terms of biogenic grain size distribution because calcium carbonate constitutes such a small proportion of the total sample that significant errors in measurement are unavoidable. An exception to the seaward increase in mean grain size is found to the north of the limestone outcrop where fine-grained terrigenous sands are also encountered. South of the rock, the biogenic component becomes extremely coarse with a mean grain size of -0.46 ϕ.

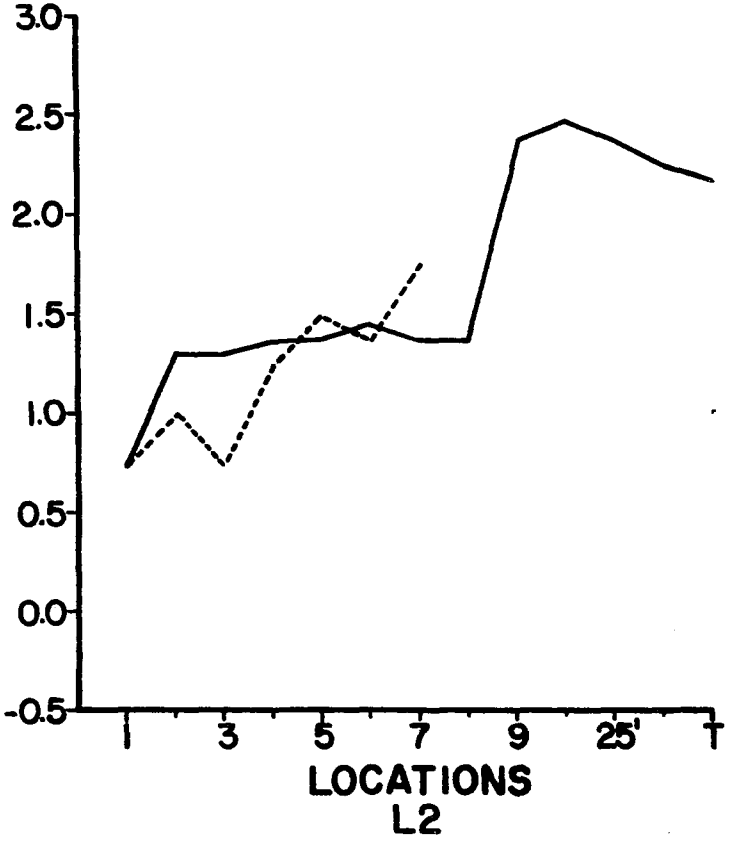
An examination of the frequency curves of biogenic grain size distribution reveals that the primary modes are, in all cases, finer than the mean grain size due to the strongly skewed nature of the distribution. The coarse fraction is expressed as several secondary modes which are consistent in size class from location to location. These modes increase in importance coastward but whether this trend continues in shallow water was not determined. While some of the coarse secondary modes contain material of gravel size, the primary modes are all composed of sand size grains. The modal classes of biogenic carbonate are comparable to those found for terrigenous grains and undergo similar trends with respect to depth and distance from shore (Figure 19). However, they are in general coarser and more irregular than terrigenous modes.

If the percent of each grain size interval that is biogenic calcium carbonate is graphed, an interesting relationship emerges (Figures 20 and 21). For most samples, grain size classes of -1.25 ϕ and larger are composed entirely of biogenic material. The percentage of carbonate drops off sharply in classes of smaller grain size to a low

Figure 19



Trends in Terrigenous and Biogenic Sediment Modal Grain Size (phi). Limestone outcrop indicated between L11 and L12.



Trends in Terrigenous and Biogenic Sediment Modal Grain Size (phi).

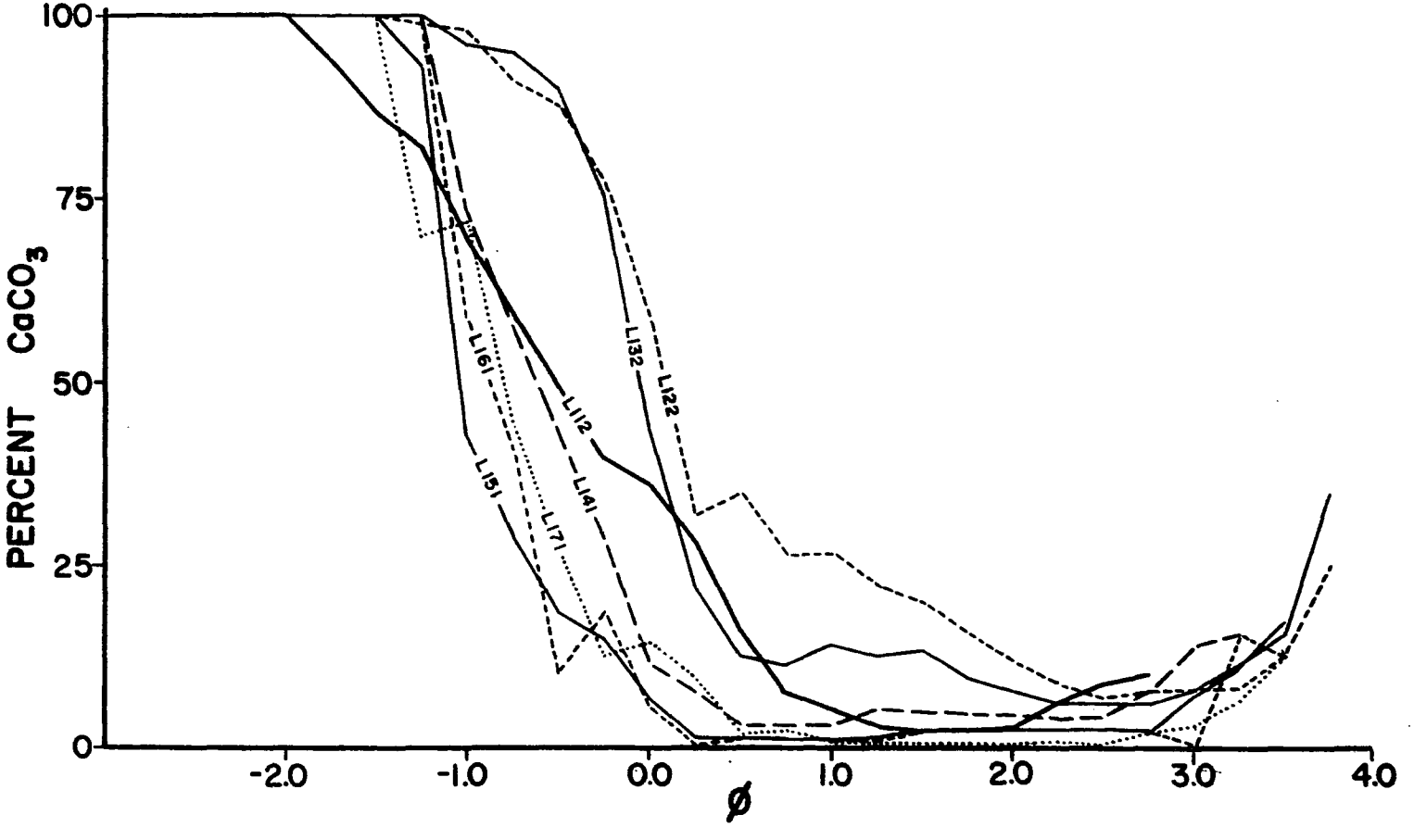


Figure 20. Weight Percent of $CaCO_3$ in Sediment Grain Size Intervals - Line L1

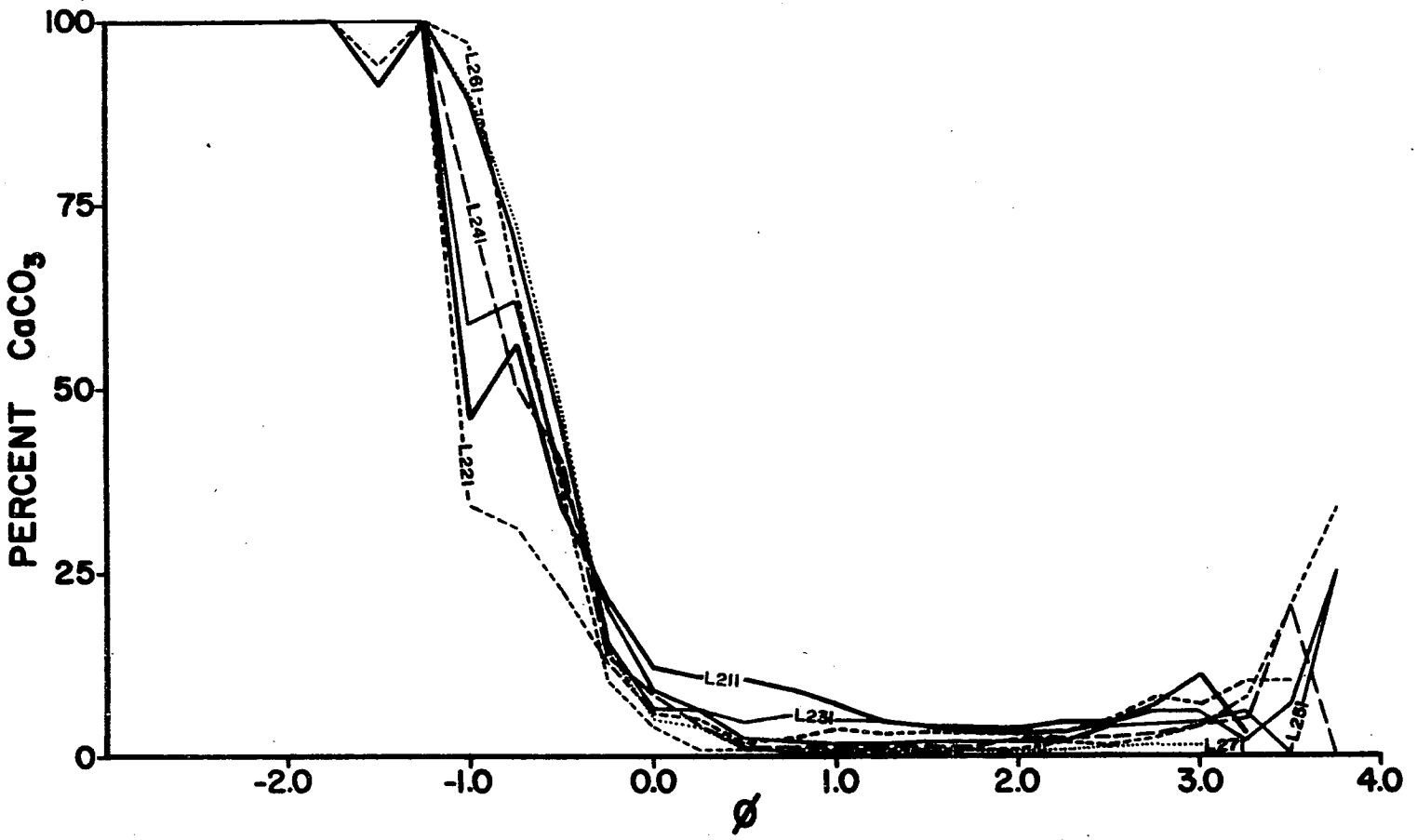


Figure 21. Weight Percent of $CaCO_3$ in Sediment Grain Size Intervals - Line L2

minimum value which continues through those grain size intervals which contain the modes for both carbonate and clastic grains. The significance of this relationship will be discussed later.

Under the binocular microscope it is evident that biogenic grain size is related to grain type. The coarse sand sizes and larger grains are either whole shells or large fragments of mollusks, echinoids, and coralline algae. Bryozoa, barnacles, and other crustaceans are minor contributors. Medium-sand-size biogenic grains are composed chiefly of molluscan fragments, juvenile bivalves, micromollusks, and echinoid fragments. In the fine sand fraction Foraminifera and ostracods become important contributors.

Limestone

The limestone outcrop covers about one acre of seafloor near the seaward end of line L1 (Figure 5). It is a low relief exposure of carbonate-cemented coquina and quartz sand. The topography developed on the seafloor consists of depressions and holes around and between the limestone blocks rather than projections of the rock above the surrounding surface. The outcrop is not continuous, but is composed of a number of more or less isolated patches of rocky bottom separated by areas of coarse sand and shells. Poor visibility thwarted efforts to determine the configuration of the outcrop with greater precision.

After detailed investigation it became clear that much of the limestone is not *in situ*, but rather consists of fragments and rubble surrounding several core areas where the rock is in place. Many of the smaller rubble fragments are rounded and covered with encrusting coralline algae. The surface of larger blocks is intensely corroded and

friable, and so abundantly inhabited by epifaunal species that a detailed description of sedimentologic features in the field was not possible.

In hand specimen, the fresh limestone surface sometimes reveals crude small-scale laminations of alternating biogenic carbonate and coarse angular to rounded quartz sand. The interior of larger rock samples is well cemented, but near the surface the cement is degraded and the limestone is more porous and friable. Analysis of the total calcium carbonate percent indicates that 66 to 75 percent, by weight, of the limestone consists of biogenic grains and cement. The size frequency distribution of the terrigenous grains, predominantly quartz, was found to be strongly bimodal with a very coarse sand mode at 0.0 ϕ and a fine sand mode at 2.25 ϕ (Figure 11).

In thin section, biogenic and quartz grains are cemented by sparry calcite. Under the scanning electron microscope the cement is typically scalenohedral in crystal habit (see Plate 1). Analysis with infra-red spectrophometry and the electron microprobe shows the cement to be low-magnesian calcite. A crust of fine calcite spar (5-10μ) is developed on biogenic grains which is followed by a druse of larger calcite crystals (15-50μ) when open cavities and interstices are present adjacent to biogenic grains. No such crust is found on quartz grains; calcite which occurs adjacent to this grain type is equant spar (15-100μ); it also fills the interstices in well cemented samples but is confined to grain contacts and irregular patches when the rock is friable.

Biogenic grains consist predominantly of mollusk fragments and branches and fragments of a *Goniolithon*-like coralline alga *(?Neogoniolithon* sp.) with foraminifera and echinoid fragments as minor constituents. There has been little recrystallization or replacement of the

biogenic grains, although some mollusk fragments appear degraded and micritized. Syntaxial overgrowths on echinoid fragments are common and crystallization of calcite druse in optical continuity with radial crystal elements of planktonic Foraminifera was noted.

Coarse quartz sand grains are generally more rounded than the angular to subangular fine quartz grains. Replacement of quartz by calcite has occurred at grain boundaries and along fractures contributing to the angularity of the smaller grains.

The rock is described as a quartzose biosparite (Folk, 1959) or a fossiliferous quartzose lime grainstone (Dunham, 1962).

Fossil molluscan shells were recovered from the limestone samples or were found free in the surrounding sediments. Fossil material was distinguished from younger shells by the presence of cemented grains adhering to the surface of the shell or in the case of gastropods by discovering cemented grains and calcite spar in the interior. The preservation of fossil material ranged from good to poor often with only a mold remaining. Identifiable fossils include the following taxa:

Bivalvia

Glycymeris cf. *americana*
Chione intapurpurea
Transennella sp.
Aequipecten gibbus
Strigilla mirabilis
Trigonocardia media
Chione clenchi
Laevicardium pictum
Laevicardium laevigatum
Corbula sp.
Lucina pensylvanica?

Gastropoda

Torcula acropora
Conus floridanus
Cerithium floridanum
Niso interrupta
Terebra dislocata
Busycon sp.
Olivella mutica?

Scleractinia

Dichocoenia cf. *D. stokesi* *?Dichocoenia* sp.

Bryozoa

Discoporella umbellata

Echinoidea

?Louvenia sp. fragments

Corallinacea

?Neogoniolithon sp.

Crustacea

Barnacles

Discussion

Terrigenous Sediment

Terrigenous sediment in the research area can be described in terms of five grain populations (hereafter referred to by number) whose textural characteristics reflect both their source and the influence of the present hydrodynamic regime: 1) fine sand of the upper shoreface, 2) medium sand of the lower shoreface and inner offshore sand plain, 3) coarse sand of the offshore sand plain, 4) and 5) fine and coarse populations respectively, occurring as terrigenous quartz grains in the lime grainstone.

Upper Shoreface Sands

Gorsline (1966) described the coast from Cape San Blas to Mobile Bay as constituting a single sand transport cell. Wave generated longshore currents, with velocities of 30 to 150cm/sec, drive sand west from

Cape San Blas along the coast to accumulate on prograding spits and bars west of Pensacola. Gorsline remarked on the textural homogeneity of the beach sands along this coast in spite of wide variations in impinging wave energy. This observation suggests that beach texture is not a direct function of wave height but is related to longshore current velocity and source, that is, the sands of the Apalachicola Delta. Measurements of coastal erosion and deposition indicate that the coastline is near equilibrium at present, with degradation during periods of intense wave activity being balanced by aggradation during calm weather.

The study area is located in the center of this general circulation system. Since the coast is at equilibrium, Moreno Point and the adjacent mainland coast are acting as conduits for longshore drift with little net deposition of sand. The westerly transport of sand occurs primarily in the landward trough of a submerged offshore bar which parallels the coast about 300 to 400 feet from the beach. The morphology of the bar has been observed to vary considerably with variation in wave energy. The crest is subdued during periods of calm weather but following storms it may be aggraded to within 4 to 5 feet of the water surface. In such a case, the landward slope of the bar was observed to be very steep, perhaps at the angle of repose, while the seaward slope of the upper shoreface had undergone erosion as evidenced by the exposure of mottled burrowed sediment on the seafloor. Sand from the upper shoreface was probably carried coastward and deposited on the crest and landward face of the bar.

During periods of high wave-energy sand is transported coastward or longshore. These grains may come to rest on the bar crest or landward trough or on the beach foreshore. Fine grains are maintained in suspen-

sion by turbulence and carried over the bar crest into deeper water where they are deposited. The mechanisms involved in this transport will be discussed later.

The general concurrence of modal and mean grain sizes of sands shallower than 35 feet suggests that these sands are a genetic unit, owing their general texture to their main source, the westerly longshore drift system described by Gorsline (1966) and Tanner (1962). Other secondary sources may include the bluffs of Quaternary sands exposed along the Gulf coast to the east. These bluffs are clearly wave cut and would yield sands which are texturally similar to those of the present beach. The extent, if any, to which these bluffs are now receding is not determined. Kwon (1969) believes that they are now stabilized. Fine sand may also be contributed to the nearshore zone by transport from offshore; the magnitude of this contribution cannot be assessed. The seaward fining trend for sands of population 1 is a response to physical transport processes in the nearshore zone.

Lower Shoreface and Offshore Sands

The limit of significant deposition of sand supplied by longshore drift occurs at about the 45 foot isobath where bimodal sands are found (L29, Figure 10) which mark the transition to population 2. Population 2, the medium sands of the lower shoreface and inner shoreface sand plain, and population 3, coarse sands of the offshore sand plain, are clearly anomalous in terms of classic concepts of the marine profile of equilibrium and seaward fining trends predicted by that model. Anomalous sands of this type are not unique to the research area. Emery (1968a) estimated that 70 percent of the world's continental shelf areas are covered with

coarse sands which are texturally unrelated to the present environment. Others (Frank and Friedman, 1973; Nasu, 1964; Kofoed and Gorsline, 1963; Tanner, 1959; and Vause, 1959) have related the occurrence of coarse grained sediments on the continental shelf to alluvial deposition during periods of increased gradient and eustatic sea level lowering. The abundance of very coarse sand and larger grains in populations 2 and 3, particularly in the deeper water coarse sands, indicates a depositional agency of higher energy than is available in those water depths today. The results of this study suggest that the texture of these medium and coarse sands reflects, in part, textures inherited from previous depositional environments and, in part, modifications produced during Holocene sea level rise and by present marine hydrodynamics.

The investigations of Hyne and Goodell (1967) have demonstrated that the research area and the adjacent shelf were highly dissected by stream valley systems in addition to or tributary to the entrenched valley of the Choctawhatchee River (see discussion of the Holocene history). The discovery of submerged forests on the inner continental shelf (Shumway, 1961) of Late Pleistocene age indicates that much of the present shelf topography is relict. Moreno Point contains remnants of a former valley system which is now expressed as lakes and bayous or marked by dense vegetation. The bathymetric reentrant in the research area (Figure 3) may be the topographic expression of an Early Holocene stream valley. Population 3 may then be alluvium which was redistributed and modified by coastal processes during the Holocene sea level rise. The sediment is now exposed on the seafloor as a blanket of coarse-grained sand subject to further reworking.

An alternative explanation is offered for population 2. The Early

Holocene offshore bar described by Hyne and Goodell (1967), now submerged to 62 feet about 5 miles south of the research area, must have developed a bay or lagoon on its landward side as sea level rose. The relict fauna collected near the lime grainstone outcrop attests to such a water body. *Chione cancellata* shells, which are an important component of that assemblage, have been radiocarbon dated at 9070 ±320 years BP. Alluvial sediments which had previously been deposited subaerially were then submerged beneath about 30 feet of water in the center of the bay, judging from present relief. If the bar is reconstructed to -55 feet, the shoreline of the resulting bay would have occurred at about the present 60 foot isobath. The bay would have existed as a relatively protected body of water with an irregular shoreline of drowned stream valleys. As the Holocene sea level rise proceeded, the offshore bar became eroded and submerged about 5000 years ago (Hyne and Goodell, 1967). The submergence of the bar would have led to vigorous wave attack of the sediments of Moreno Point and the mainland to the east. The eventual result was the straightening of the coastline and the removal of sand to the west by the longshore drift system (Kwon, 1969). The increase in sand supply led to the development of Santa Rosa Island which eventually closed off Choctawhatchee Bay less than 3300 years ago (Goldsmith, 1966).

Water-well data near the research area indicate that beneath the thin veneer of Holocene fine-to-medium sands of the present beach and dune complex are medium-to-coarse sands of Pleistocene age. The retreat of the shoreface under wave attack during the Holocene transgression exposed these older alluvial and marine units. Population 2 may therefore represent a contribution to the present marine sediments by the underlying Pleistocene strata of the shoreface. These strata are over-

lain on the upper shoreface by fine sands of the present longshore drift system and on the offshore sand plain by coarse sediments of alluvial origin.

Limestone-derived Terrigenous Grains

Superimposed on the general distribution of the genetic units described above are the contributions of populations 4 and 5. The coincidence of the fine terrigenous mode from the lime grainstone with the mode of the fine-sand body to the north suggests that this body is an accumulation of fine clastic material derived from submarine erosion of the limestone and carried coastward by bottom currents. The gradual increase in modal and mean grain size with distance from the outcrop is compatible with this hypothesis as the contribution of fine grains from the outcrop diminishes to the north. Submarine erosion of the limestone is being accomplished by the activities of boring organisms, such as clinoid sponges and bivalves, which preferentially destroy biogenic grains and cement and release quartz grains for transportation. As fine grains are dispersed northward and deposited they are mixed with the existing sediment by bioturbation. The hydrodynamic mechanisms responsible for the coastward transport of limestone-derived grains will be discussed later.

Coarse terrigenous grains from the limestone have possibly been incorporated into the sediments surrounding the outcrop as suggested by the secondary coarse mode in these sands. The dispersal of very coarse sand and larger grains in this setting may have involved subaerial processes active in the past. A consideration of the geologic history of the lime grainstone is necessary to assess this possibility.

Lime Grainstone - Geologic History

A study of the species of mollusks and other groups included as fossils in the rock indicate that the quartzose lime grainstone was deposited in an open marine environment in water depths of at least 70 feet. Many other outcrops of quartzose limestone are known to the author on the adjacent continental shelf. The bathymetric relationships of these outcrops suggest that they represent remnants of a once more continuous marine lime-sand body. The projected dip of this lime-sand is consistent with the general seaward slope of the present continental shelf.

Hyne and Goodell (1967) determined a radiocarbon age of 22,042 years BP for a limestone fragment of similar lithology dredged about 9 miles south of Destin in 85 feet of water. A coral head, presumed to be part of the fossil assemblage from the limestone, was dated as at least 37,000 years old in the present study. The age of 22,042 reported by Hyne and Goodell is a minimum age since they apparently analyzed a bulk limestone fragment containing both biogenic grains and cement. Milliman and Emery (1968) estimate that sea level was near its present position 30,000 to 35,000 years ago. Their estimate is compatible with species composition and age of the limestone fossil material. This sea level maximum corresponds to the mid-Wisconsin transgression and Pamlico terrace surface of Marsh (1966). Subsequently, the sea fell to a low of -130 meters 16,000 years ago.

The West Florida shelf was therefore receiving marine sediments of Pamlico age about 35,000 years BP. The lime grainstone found on the shelf in and adjacent to the research area was probably deposited at that time. However, the cement type indicates that it was not

cemented until exposed to subaerial conditions and meteoric waters (Bathurst, 1971). The discrepancy between the age of 22,042 reported by Hyne and Goodell and the hypothesized age of 35,000 years BP may be explained by the inclusion of much younger cements in their analysis.

Drawing on all lines of evidence the following sequence of events is suggested. The quartzose lime-sand was deposited on the inner continental shelf during the mid-Wisconsin (Pamlico) transgression. With subsequent lowering of sea level the sand was cemented and remained exposed in the research area until about 9,000 years ago, judging from published curves of Holocene sea level rise (Milliman and Emery, 1968, and Curry, 1960) and the radiocarbon age of relict bay species. During this period of exposure the limestone was eroded and dissected by the stream valley systems described previously. The Holocene transgression subjected the eroded limestone outcrops to wave attack. Limestone fragments, rubble, and fossil material were scattered adjacent to the outcrop to form an apron of coarse material. Distinct layers of rubble and poorly preserved Early Holocene bay and open marine shells are found to the north and west of the present outcrop in the research area, beneath the fine sands occurring there now. Coarse quartz grains from the eroded lime grainstone could have been incorporated into the surrounding alluvium that was being submerged beneath the rising sea. At present, the grainstone outcrops exist as isolated outliers surrounded by rock fragments, rubble, shells, and coarse sand.

Skewness

Trends in moment skewness reflect the distribution and mixing of the above-mentioned grain populations or genetic units. The symmetrical

size frequency distributions (Figure 10) of the medium sand (population 2) probably indicates the initial size composition of its source, little modified by present hydrodynamics. Folk (1968) suggested that single-source sediments are generally normal in size frequency distribution. The progressive increase in positive skewness in this facies towards the coast results from the deposition and admixture of fines either carried down the shoreface from the coast or winnowed from the offshore sands and transported landward. When the fine sands of population 1 assume dominance, as at locations L29 and L19, the secondary mode of median sand contributed by population 2 causes the sign of skewness to change abruptly from positive to negative. The negative skewness of the more coastward locations is probably related to the winnowing and removal of fines from those sands (Duane, 1964) with the minimum skewness occurring on the bar crest where wave energy is concentrated.

Northward of the limestone, negative skewness reflects the admixture of the indigenous populations of medium and coarse sand with the abundant supply of limestone-derived fine sand. The contribution of populations 2 and 3 appears as a coarse tail on the size frequency distribution of these fine sediments. With distance from the outcrop skewness becomes less negative and finally symmetrical as the supply of fine sand diminishes.

It is difficult to make any definite statement about the meaning of observed skewness in the coarse sand facies due to the small number of samples collected there. South of the lime grainstone the coarse sands are somewhat negatively skewed perhaps caused by incorporation of limestone-derived, very coarse sand and larger terrigenous grains. At location L21 the coarse sands of population 3 are positively skewed.

Skewness at that location may reflect the admixture of grains from the adjacent medium sand. A wide zone of mixing between the coarse sands of hypothesized alluvial origin and the medium sands is suggested by the bimodal nature of the size frequency distributions at locations L22 and L23. Seaward transport of medium sand may have occurred during the Holocene sea level rise as waves redistributed the sand eroded from the retreating shoreface, giving rise to the present distribution.

The area of positive skewness west of the outcrop is of uncertain origin or extent. It may represent the distal western edge of the limestone-derived, fine sand body. In that case, one interpretation is that positive skewness is produced by infiltration of those fines into the medium sands of population 2. However, observation suggests that this area is undergoing sediment movement and winnowing at the present time. The surface sediments appear coarser than those found at depths of several inches in ripple troughs. Exposed polychaete worm tubes also attest to an active sedimentary environment. The medium sands at location S-1 therefore seem to be derived from the subjacent fine sands with positive skewness resulting from incomplete winnowing.

Biogenic Sediment

Biogenic Percentage

The weight percentage of biogenic material in marine sediments, expressed as the percent calcium carbonate, appears to be inversely related to the rate of terrigenous sedimentation. This conclusion was reached by Pilkey et al. (1969) for the Atlantic shelf and by Kofoed and Gorsline (1963). The very low percentage of biogenic material on the

shoreface may reflect active sedimentation there while higher percentages on the offshore sand plain indicate very low rates of deposition. However, other factors contribute to the observed trend of seaward increase. Productivity in certain groups, such as Bryozoa, coralline algae, Foraminifera, and ostracods, increases in deeper water where decreased disturbance by wave-generated bottom currents creates a more favorable environment. Of great importance in the vicinity of the limestone outcrop is the relict fauna of bay and inlet species which constitutes a large percentage of the biogenic material found there.

Biogenic Sediment Texture

Several factors act to control the modal and mean grain sizes for assemblages of biogenic grains: 1) productivity of organisms and size of associated hard parts, 2) shell structure as it relates to the size and shape of units produced by breakage, 3) size sorting of biogenic material by currents.

Productivity is not uniform among the diverse groups of organisms present in the research area but is dependent on depth-related environmental factors and substrate. The size of shells and tests produced by these organisms differ markedly. For example, Foraminifera and ostracod tests are predominantly of fine sand size while the other major biogenic contributors, mollusks, echinoids, coralline red algae, and bryozoan colonies are for the most part of granule or larger size (>2.0mm). Micromollusks and juvenile mollusks are of intermediate size but are relatively minor constituents. If the size distribution of biogenic material was solely related to factors of productivity and size, a strongly bimodal distribution would be expected with a very coarse mode

provided by the larger groups and a fine mode produced by ostracods and Foraminifera. This is not the case. A single mode in the fine to medium sand size range dominates the size frequency distribution at all locations, particularly in deeper water, except south of the outcrop where coarser biogenic material predominates. The very coarse biogenic mode there results from the abundance of coarse relict fauna alluded to previously.

Fragmentation of biogenic material may produce characteristic modes which reflect the size of certain fundamental architectural and crystal units. Tumbling barrel experiments performed by Force (1969) produced overlapping populations of molluscan skeletal elements. Fragments of sand size or larger were predominantly first order shell layers. Smaller fragments were sublayers or crystal units. However, the overall effect of the experiment was to generate a continuous size spectrum of molluscan fragments. Hoskin and Nelson (1971) found that the initial disintegration of barnacles in the littoral zone produced fragments with a mode at 12mm. This size distribution was not reflected in the biogenic material, mostly barnacle debris, which accumulated in the adjacent marine sediments. They concluded that natural processes produce a continuous range of biogenic fragment size for that material. This conclusion was also supported by samples from Sanabel Island, Florida, which indicated a rectangular size distribution of molluscan fragments. On the other hand, the investigations of Folk and Robles (1964) on Alacran Reef indicate that calcareous algae and coral disintegrate to produce characteristic modal size classes reflecting microstructure.

From the above discussion it may be inferred that the major contributors of coarse biogenic detritus, mollusks and echinoids produce no

characteristic size modes upon fragmentation. However, the species of coralline algae, of *Goniolithon*-type, found abundantly in deeper water in the research area,probably develops a mode of coarse sand size from the breakup and abrasion of its branches. Rounded coralline algal grains are an important component of the lime grainstone. The consistent coarse secondary modes of biogenic grain size distribution may represent a contribution of that type.

Nevertheless, the dominant influence on the size distribution of biogenic material in the research area is, or has been, size sorting in a hydrodynamic system. This assertion is supported by the constant proportionality of carbonate and clastic across modal grain size classes (Figures 20 and 21). The implication is that biogenic and terrigenous grains are retained or accumulated in the depositional environment in an equilibrium situation where an increase in biogenic grains of a certain size is offset by an increase in the supply of terrigenous grains of the same or similar size. Clearly, this is a result of sediment transport processes. If high productivity was responsible for the modal size, an increase in supply of modal biogenic grains would not be compensated for by an increase in terrigenous material, and the percent calcium carbonate for that size interval would increase. The increase in carbonate percentage noted in the very fine sand fraction of most samples is probably a result of measurement error due to very low total class weight.

Relation of Terrigenous and Biogenic Sediment Textures

The general concurrence of biogenic and terrigenous modal grain size trends is highly suggestive of a common origin for modes of both components. It is unlikely that variations in productivity, initial

shell size, or fragmentation could produce such regular changes in light of the previous discussion. The conclusion is that size sorting by physical processes in the depositional environment is responsible for the observed trends of biogenic modal grain size. Pilkey (1964) found similar relationships of biogenic fragmental grains and terrigenous sediment on the Atlantic shelf and inferred that the common size distribution of these two fractions was due to transportation processes. Hoskin and Nelson (1971) and Force (1969) reached the same conclusion for their areas of research.

Concurrent size sorting of biogenic and terrigenous grains implies active sediment movement at all depths in the research area. Observation indicates that bottom sediments shallower than 40 feet are often disturbed by waves. There is some evidence for considerable sediment movement in deeper water.

Evidence for Deep Water Sediment Movement

Large-scale oscillatory ripples, with wave lengths of 2 to 3 feet and amplitudes of 4 to 6 inches, are often found on the offshore sand plain to depths of at least 85 feet (see Plates 9 and 10). Comparable ripples have been described by Tanner (1959) and Vause (1959) at depths of 65 feet off the Apalachicola Delta. In the study area the ripple crests are always oriented parallel to the coast indicating that at the time of their formation incident wave energy was directed normal to the shoreline. When fresh, the ripple crests are regularly spaced and extend continuously for distances of over 50 feet. Burrowing organisms rapidly destroy these sedimentary structures and produce a hummocky microtopography. The common observation of large-scale ripples therefore attests

to continual ripple formation in the face of continual biologic destruction.

The wave length and amplitude of oscillatory sand ripples have been related to the variables of texture, fluid motion, and depth. Vause (1959) observed that large sand ripples are confined to medium and coarse sands of the lower shoreface and offshore sand plain. Smaller, more irregular ripples are developed in the upper shoreface fine sands. Tanner (1959) found a direct relationship between ripple wave length and water depth and calculated a logarithmic function based on his empirical data. However, Trenhaile (1973) discovered that ripple wave length is inversely proportional to depth but positively correlated with wave height. The findings are resolved when Tanner's data are related to increasing grain size as was the case in his research area. Wave length then increases with increasing grain size as predicted by Trenhaile since greater orbital velocities and thus greater wave heights are required to form ripples in coarse grained sediments.

Other evidence of sediment movement exists in the form of exposed polychaete worm tubes. Certain species of polychaete construct tubes armored with shell fragments. They live most abundantly in the fine sand substrate adjacent to and north of the limestone outcrop. Normally their tubes extend vertically to the sediment-water interface. Where rubble and shell layers exist beneath the fine sand, the tubes are anchored to that material. Surprisingly, the fine sand is unrippled while adjacent areas of coarse sand have been modified by the large scale ripples described above. Apparently the cohesive nature of the sand and the abundance of polychaete tubes bind the sediment and prevent its movement even in severe weather (e.g., hurricane Agnes, 1972). However, areas of

erosion of this fine sand body have been found where a residuum of coarse rippled sand remains (see Plate 10). In these areas polychaete tubes project one to two inches above the surface and in some cases are disoriented by active sediment movement.

Based on these observations it is clear that sediment movement is occurring today on the lower shoreface and the offshore sand plain, but the magnitude, if any, of net sand transport is in question. A consideration of wave mechanics, sediment transport theory, and the wave energy spectrum in the study area will be undertaken in an effort to resolve this question.

DYNAMICS OF SEDIMENT TRANSPORT

Bottom currents and associated sediment transport in the research area will be investigated with two objectives in mind. First, to provide a qualitative explanation of observed sediment grain size and compositional distributions, and, second, to develop a predictive model for the transport and dispersal of coarse biogenic detritus in the shallow, open marine environment. The following discussion is not intended to be a comprehensive review or rigorous application of hydrodynamic theory. Rather, specific semiempirical and theoretical relationships will be applied to the problem at hand.

Transport Mechanisms

Sediment transport mechanisms in the marine environment have been reviewed by Swift (1970) and Swift et al. (1971). The nearshore zone is characterized by the dominance of oscillatory and mass transport currents related to wind-generated surface waves and compensatory currents: longshore currents, rip currents, and mid-depth return flow. Creager and Sternberg (1972) concurred and placed the seaward limit of this hydraulic zone at the 50 meter isobath for the Washington shelf. However, there is little general agreement as to the dominant transport processes on the central and outer shelf. Swift (1970) and Swift et al. (1971) emphasized the occurrence of rare events which erode bottom sediment and cause the slow seaward movement of bedload by a random or probabilistic process of diffusion (Swift et al., 1972). This process is caused primarily by wave-associated bottom currents. On the other hand, Sternberg

and McManus (1972) and Creager and Sternberg (1972), based on current meter records and sediment studies on the Washington shelf, concluded that wind drift currents were the most important influence on dispersal in water depths greater than 50 meters. McClennen (1973) stressed the importance of the critical erosion velocity relative to the competence of currents versus wave processes to transport sediment on the New Jersey shelf. Where high critical erosion velocities are required, wave-associated processes dominate; where lower velocities will entrain sediment, currents play the dominant role.

In any event, the study area lies well within the wave-dominated nearshore zone. The motion of water particles beneath a passing wave-form in deep water is ideally circular with forward motion occurring under the crest and reverse motion under the trough. However, it is not a closed circle. There is a component of particle motion in the direction of wave propagation. A current vector is thereby established which leads to mass transport of water in that direction called wave drift. In shallow water the orbits of water particles assume an elliptical shape which flattens towards the bottom and near the sediment-water interface becomes largely an oscillatory forward and reverse flow. Superimposed on the oscillatory motion is the component of wave drift. Sediment entrained by oscillatory accelerations during the passage of a wave will therefore experience a net force in the direction of wave advance.

Compensatory currents are a result of the interaction of shoaling and breaking waves and the beach surface. Breaking waves are waves of translation in which water particles move forward *en masse* with the advance of the wave-form. The shoreward flow of water into the surf zone results in the elevation of the water surface at the shoreline above mean

sea level, a phenomenon termed wave set-up. To compensate for wave set-up, seaward flows are established which return water to the offshore. When waves approach obliquely to the coast a longshore current is generated with motion imparted by the translatory nature of approaching waves and asymmetry of fluid motion in the swash zone. Localized longshore currents may also develop when waves approach normal to the coast. Longshore currents are confined to the breaker zone and shoreward. The return of water to the offshore is accomplished by rip currents, which are discrete flows normal to the coast, or by a generalized mid-depth return flow.

The coast at Moreno Point is classified as a moderate energy coast (Tanner, 1960; Gorsline, 1966). According to Gorsline the mean breaker height is 35cm although this estimate is based on few data and, from observation, seems somewhat low. A more detailed discussion of the wave energy spectrum will be given later. Tides are largely diurnal (NOAA data, 1973) with average range of about 1 foot and a maximum range of 3 feet. Semidiurnal tides occur only during the equatorial phase. Current meter records are not available but it seems likely from the small tidal ranges that tidal currents are of little influence compared to wave-induced motion.

Wave-induced currents in the nearshore zone are directed normal to the coast (Swift, 1970). This assertion is supported by the alignment of ripples parallel to the coast in the study area. Longshore sediment movement is probably relatively minor beyond the breaker zone and, in any case, cannot be assessed; it will not be considered in the following treatment. A one-dimensional model of sediment transport will be developed which accounts for movement towards and away from the coast

with some discussion of its implications in a two-dimensional system.

Wave Mechanics

Theoretical formulations have been developed which describe the behavior of several types of ideal water waves. Because wave motion is complex and is influenced by interaction of wave energy with the bottom, each theory approximates the behavior of real waves only under certain conditions of wave height, wave length, and water depth. Wave characteristics and water depths in the research area require the use of theory applicable in water of intermediate depth (Inman, 1963) where $1/4<h/L_o<1/20$. Stokian waves satisfy this requirement (Ippen, 1966; Inman, 1963).

The entrainment of bottom sediment depends on the velocity of the overlying fluid. The maximum orbital velocity in an oscillatory wave regime occurs under the passing crest when the effect of mass transport and oscillatory motion are additive. At the bottom the maximum orbital velocity may be expressed as

$$U_{max} = \frac{\pi H}{T \sinh \frac{2\pi H}{L}} \quad \text{(Ippen, 1966, p. 110)}$$

This expression has found general acceptance as an approximation of fluid motion on the seafloor (Inman, 1963; Allen, 1971; Cherry, 1966). Figures 22-25 illustrate the relationship between maximum orbital velocity U_{max} and depth for any given wave height and period. The maximum orbital velocity is seen to increase exponentially with shoaling water for given wave energy. Concurrently, but not shown on the figures, mass transport velocities increase rapidly.

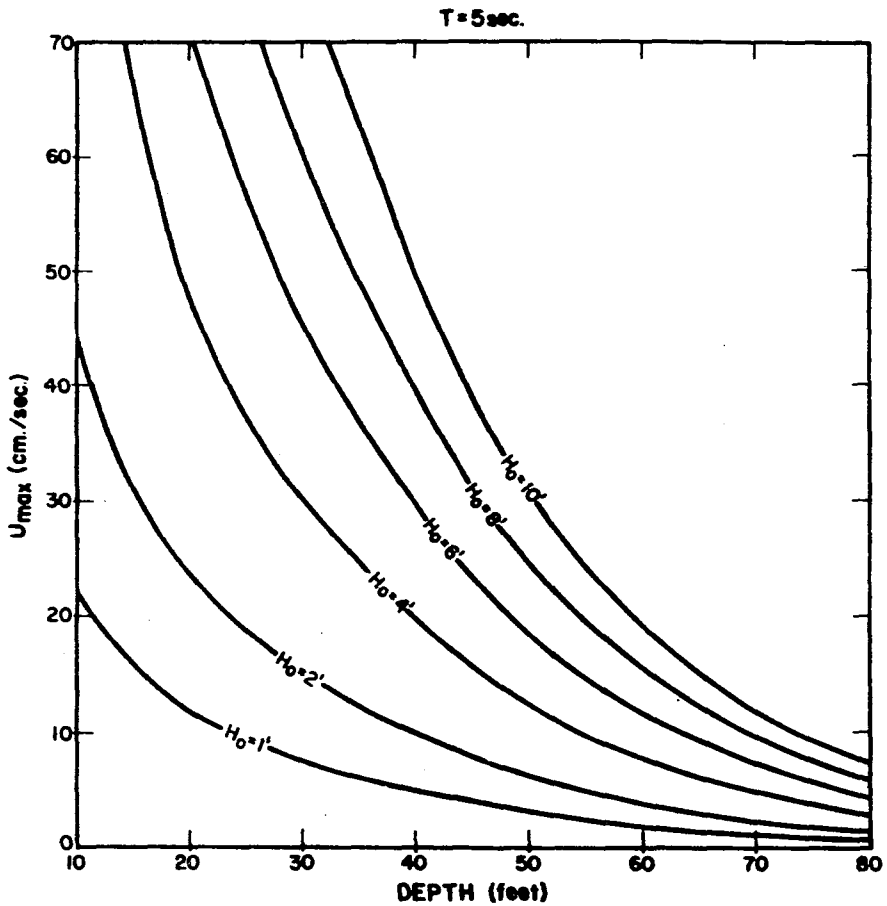


Figure 22. Maximum Orbital Velocity (U_{max}) at the Seafloor for Conditions of Wave Height (H_o), Period (T=5sec.), and Water Depth.

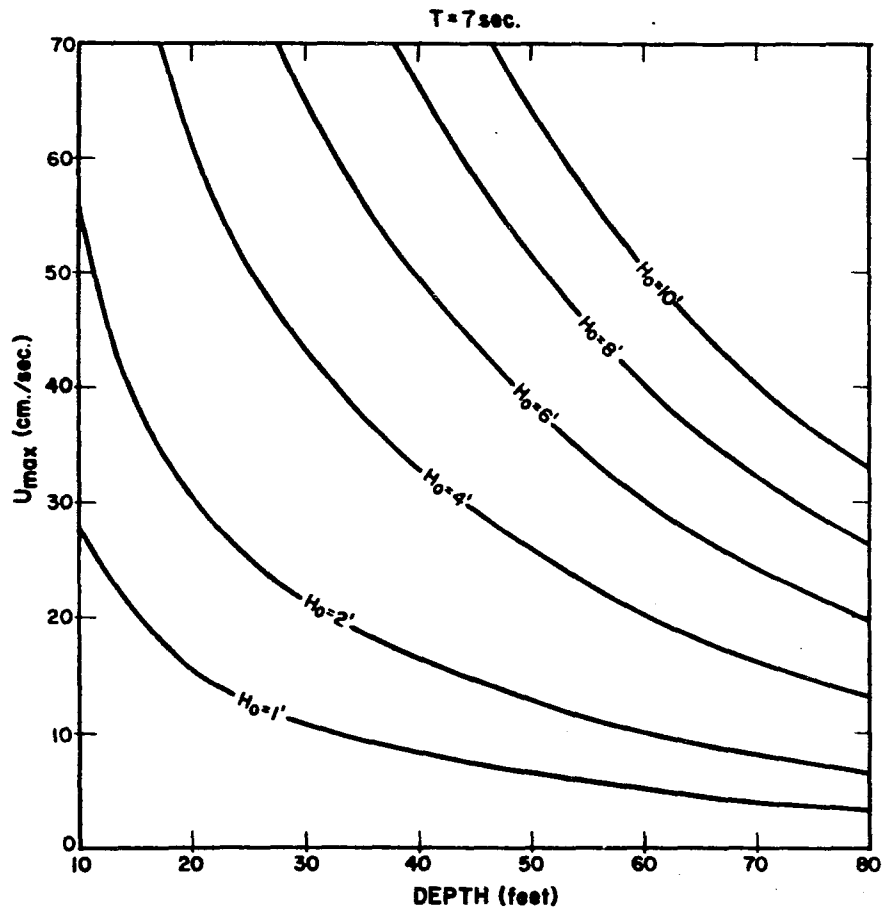


Figure 23. Maximum Orbital Velocity (U_{max}) at the Seafloor for Conditions of Wave Height (H_o), Period (T=7sec.), and Water Depth.

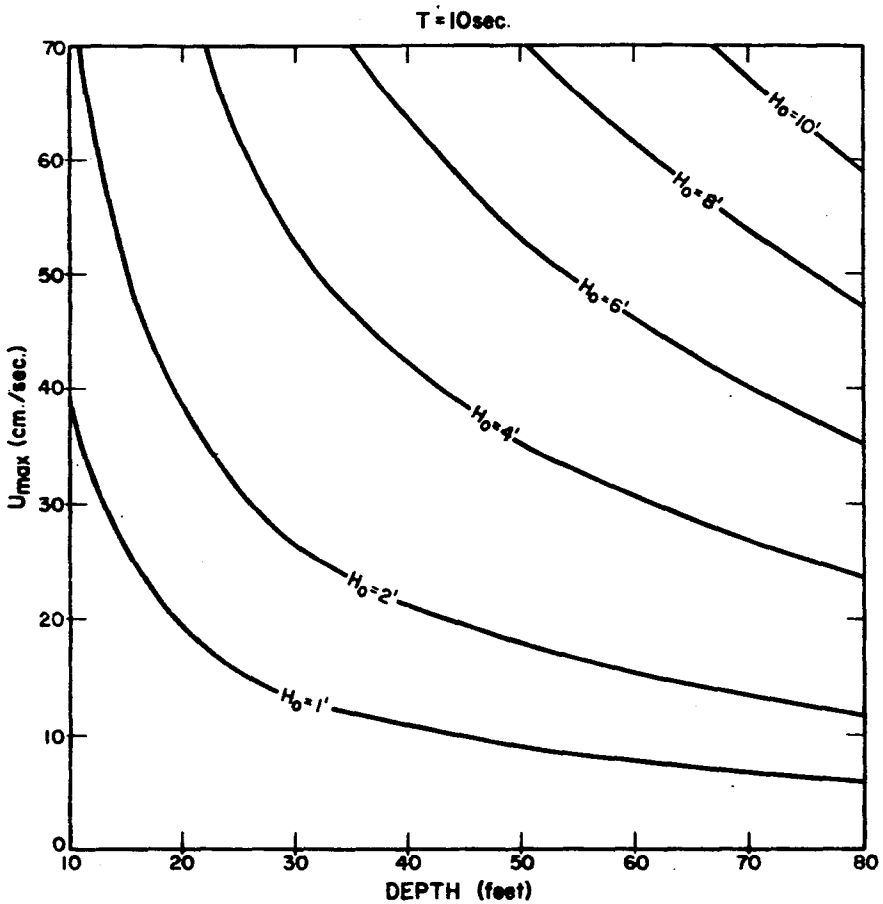


Figure 24. Maximum Orbital Velocity (U_{max}) at the Seafloor for Conditions of Wave Height (H_o), Period (T=10sec.), and Water Depth.

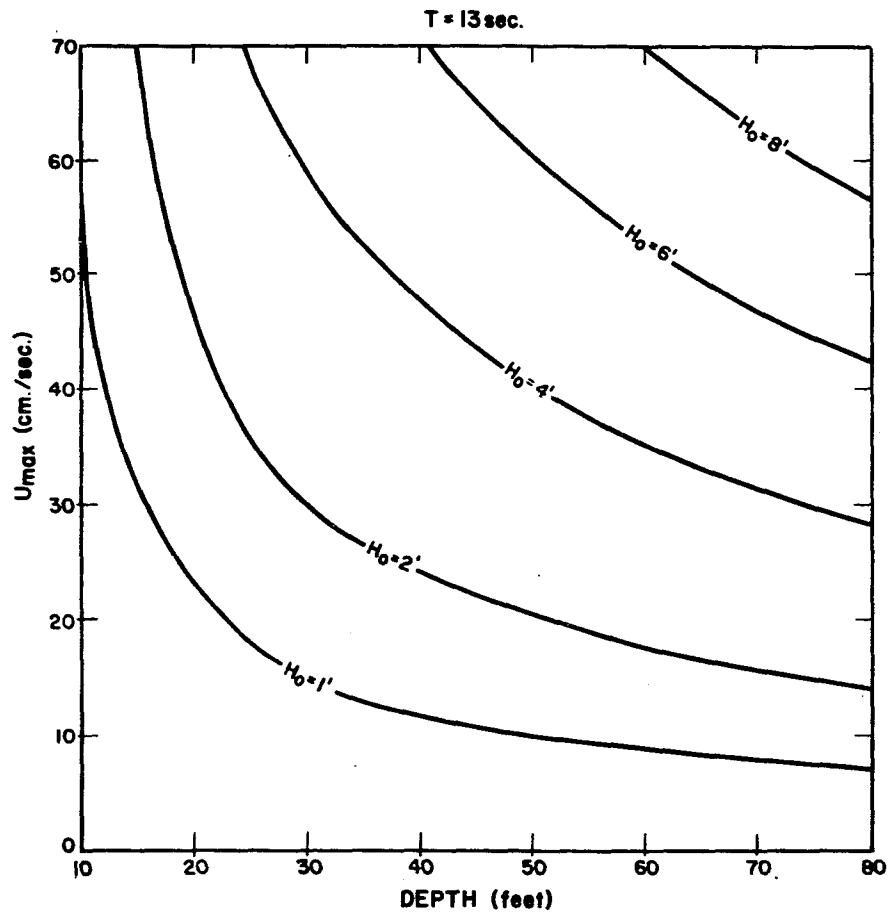


Figure 25. Maximum Orbital Velocity (U_{max}) at the Seafloor for Conditions of Wave Height (H_o), Period (T=13sec.), and Water Depth.

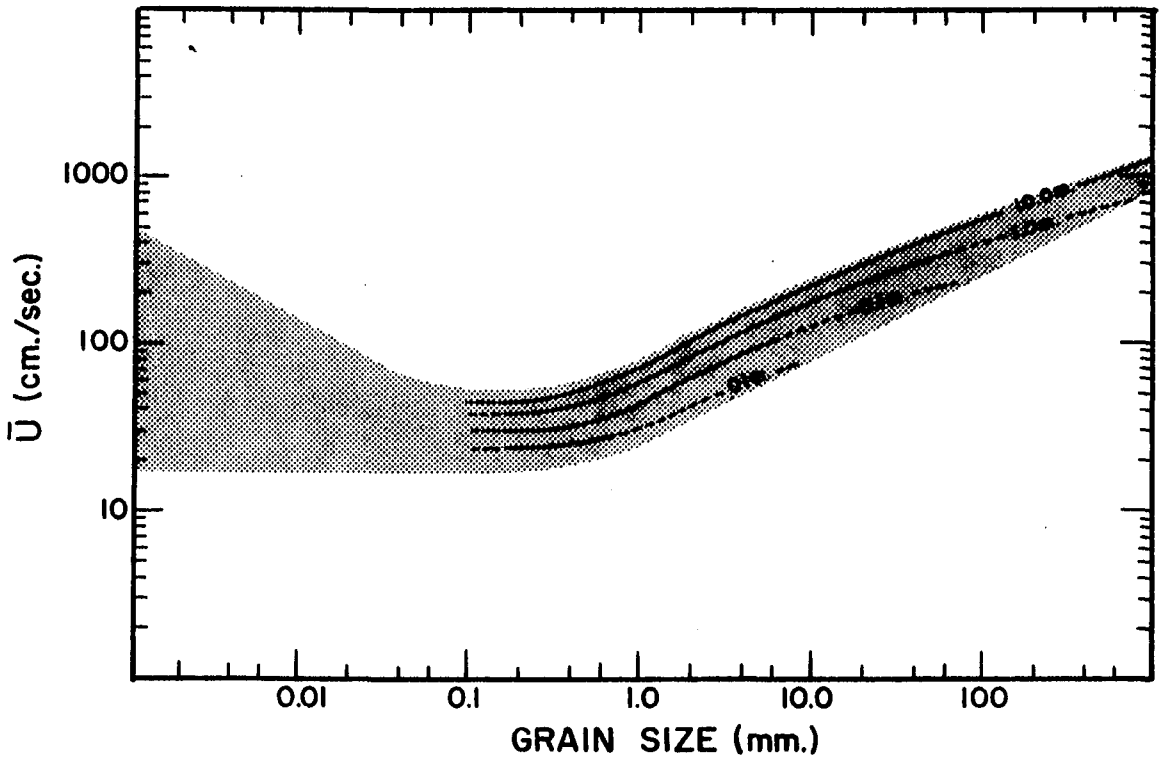
Initiation of Sediment Movement

Grain movement is initiated when the instantaneous fluid forces acting parallel to the bed exceed the gravitational forces which hold the grain in place. Sundborg (1956) found that the force required to move grains of a certain size was a function of, among other things, grain diameter, immersed particle weight, and angle of repose. He calculated this fluid force in terms of critical erosion velocity, a mean fluid velocity at which sediment grains begin to move. Sundborg constructed a series of competency curves (Figure 26) which relate U_{crit} to grain diameter. These curves are in general agreement with those published by Hjulstrom (1935). Although the curves were derived from data obtained from uniform sediments, field observations of natural sediment containing a mixture of grain sizes usually conform closely to the predicted relationship (Sternberg, 1972).

For the purposes of this investigation, values of U_{crit} were taken from the competency curve at .01m above the bed since orbital velocities were calculated at the sea floor. Values of U_{crit} for grain diameters of .1mm through 4mm were transferred to Figures 22-25. From these figures it is possible to extract data regarding the initiation of sediment movement by waves of a given height and wave length in water depths of 20 to 80 feet. The critical grain diameter D_{crit} is defined as the diameter of grains which are in incipient motion for any given U_{max}.

Equilibrium Grain Size

The quantitative theory of equilibrium grain size in wave-induced bed load transport was developed by Ippen and Eagleson (1955) and



Critical Erosion Velocity Curves (from Sundborg, 1956). Curves show the relation between grain size and critical erosion velocity for uniform material of density 2.65 g/cm^3. The flow velocity (Ū) is that at .01, 0.1, 1.0, and 10.0m above the bed. Stippled region indicates supposed boundaries for variations in critical erosion velocity.

Figure 26

restated by Ippen (1966). Assuming that grains of uniform size are in oscillatory motion on a seaward sloping surface, then the direction of net sediment transport depends on the relative magnitude of mass transport forces directed upslope (onshore) and the component of gravity directed downslope (offshore). When fluid forces F_f are greater than gravitational forces F_g net onshore transport of sediment occurs. When $F_f<F_g$ a net offshore movement results. However, when $F_f=F_g$ the sediment particles oscillate with no net transport.

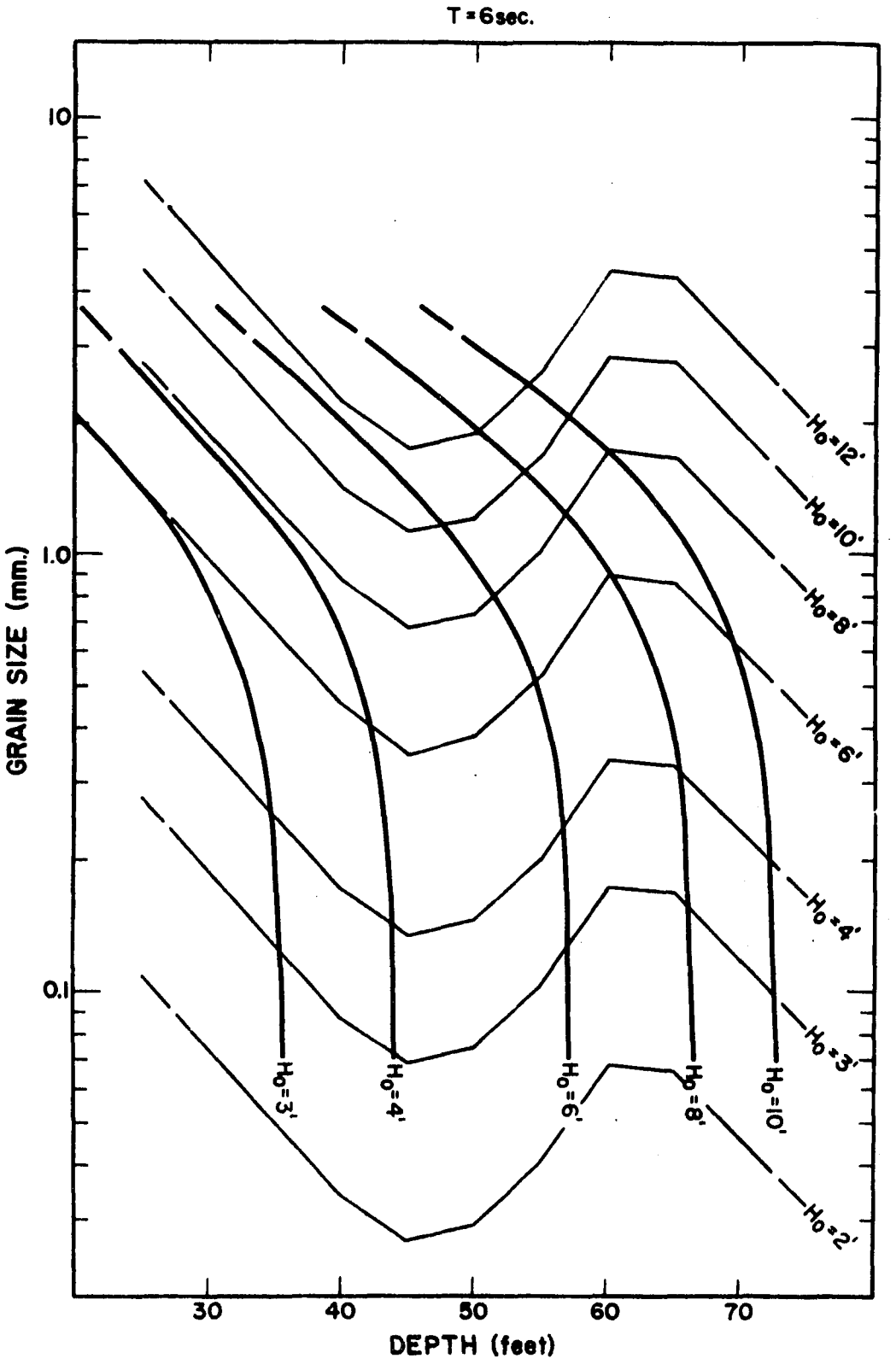
For sediment of diameter D_e, in oscillatory equilibrium, Ippen and Eagleson (1955) derived the equation

$$D_e = \left[131 \frac{H_o^2 \upsilon}{gTL_o} \quad \frac{Sf}{S_s - S_f} \quad f_1 \frac{\frac{h}{L_o}}{\sin\alpha}\right]^{7/6} \left(\frac{\pi}{\upsilon t}\right)^{2/3} \text{ ft.}$$

where $$f_1\left(\frac{h}{L_o}\right) = \frac{\text{ctnh}^2 kh}{\sinh^2 kh + k_o h}$$

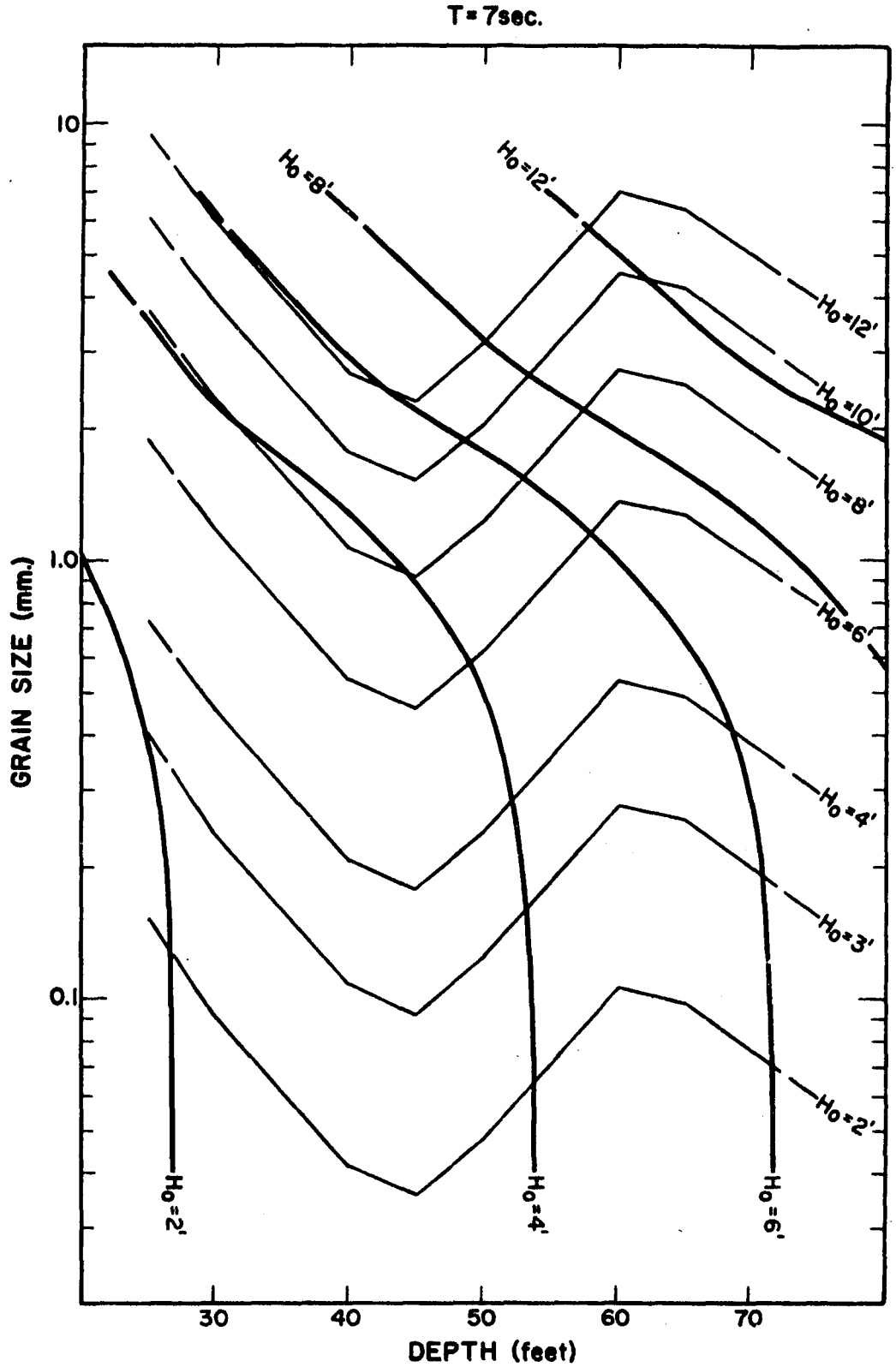
A graph is presented by Ippen (1966) from which values of f_1 (h/L_o) can be extracted.

The equilibrium diameter D_e in water depths of 20 to 70 feet for certain wave periods and heights are presented in Figure 27-30. Also shown in the same figures are curves of D_{crit} derived from Figures 22-25 for given wave characteristics. Bottom slope α was taken from bathymetry along line L2. Figures 27-30 may be interpreted from two points of view. For example, for waves with a period of 6 seconds (Figure 27) and height of 4 feet, in 40 feet of water grains less than .17mm in diameter move onshore since they are smaller than the equilibrium diameter D_e and $F_f>F_g$. Grains larger than .17mm but smaller than .66mm are transported offshore since $F_f<F_g$. Grains coarser than .66mm are not disturbed under



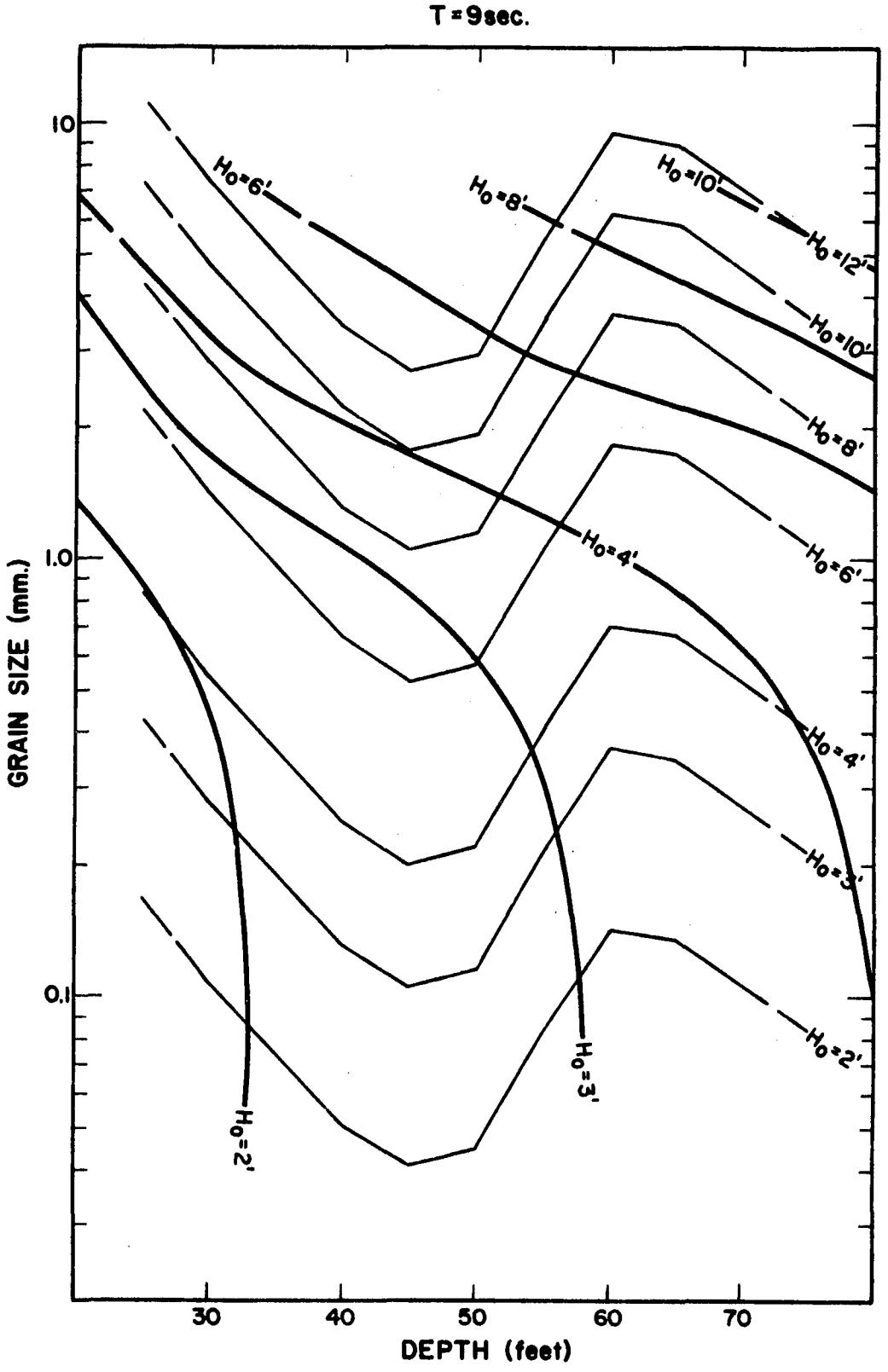
Curves of Equilibrium Grain Diameter (Light Lines) and Critical Grain Diameter (Heavy Lines) for Conditions of Wave Height (H_O), Period (T=6sec.), and Water Depth in the Research Area.

Figure 27



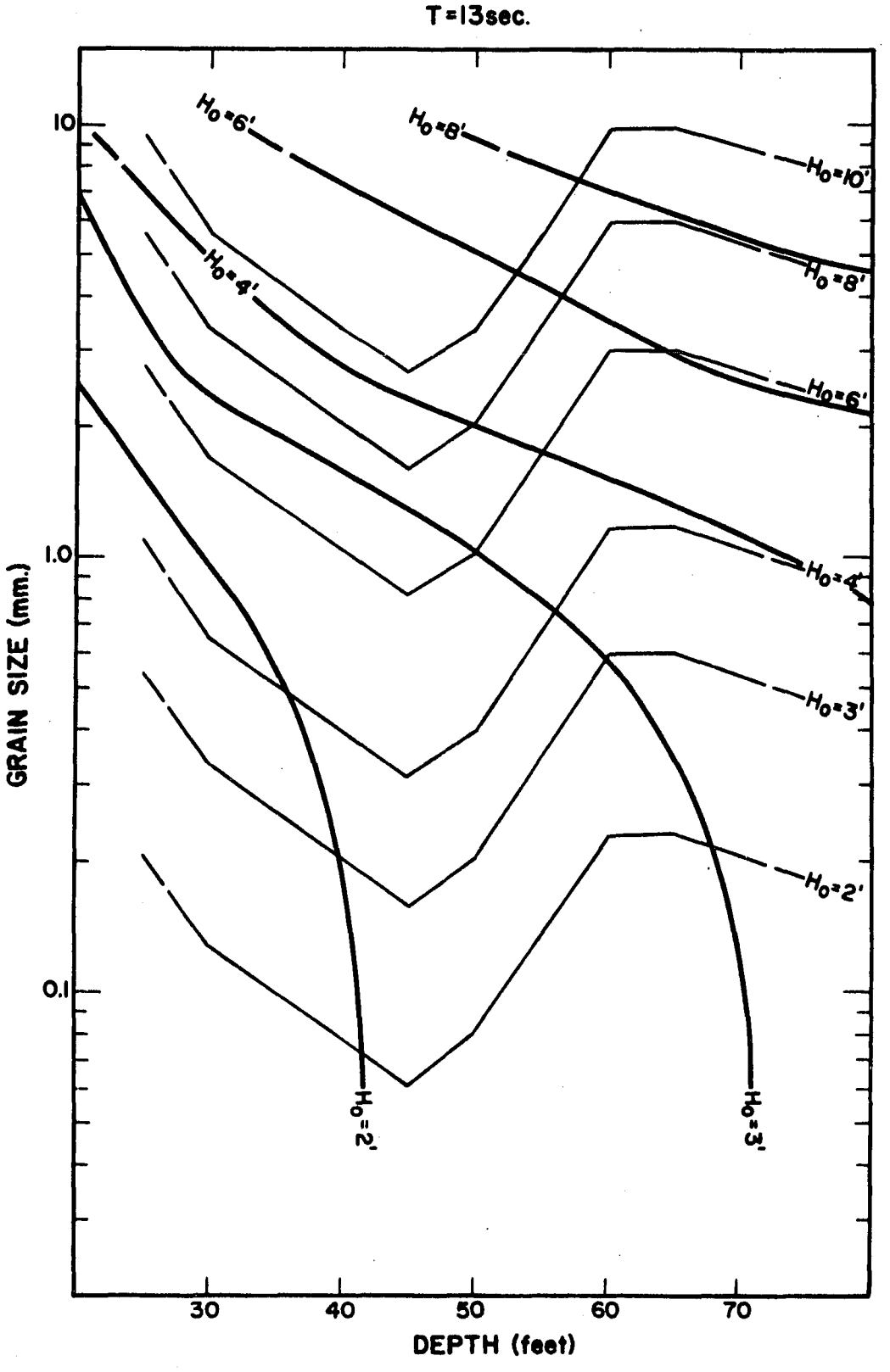
Curves of Equilibrium Grain Diameter (Light Lines) and Critical Grain Diameter (Heavy Lines) for Conditions of Wave Height (H_O), Period (T=7sec.), and Water Depth in the Research Area.

Figure 28



Curves of Equilibrium Grain Diameter (Light Lines) and Critical Grain Diameter (Heavy Lines) for Conditions of Wave Height (H_O), Period (T=9sec.), and Water Depth in the Research Area.

Figure 29



Curves of Equilibrium Grain Diameter (Light Lines) and Critical Grain Diameter (Heavy Lines) for Conditions of Wave Height (H_O), Period (T=13sec.), and Water Depth in the Research Area.

Figure 30

the given wave and depth conditions. The equilibrium grain size D_e is then .17mm when $F_f=F_g$.

On the other hand, for waves of a period of 6 seconds and height of 4 feet, grains .2mm in diameter experience no motion in water depths greater than 43.5 feet since $U_{max}<U_{crit}$ for that grain size. Between depths of 38 and 43.5 feet these grains are transported offshore since F_f is small and $F_f<F_g$. In water shallower than 38 feet, this grain size undergoes net onshore transport as F_f becomes larger and $F_f>F_g$. At 38 feet oscillatory equilibrium is reached for grains .2mm in diameter where $F_f=F_g$.

The solution of the equilibrium diameter equation is trivial for regions to the right of the D_{crit} curve for a given wave height since no motion occurs there in any case. However, it should be noted that when $D_{crit}<D_e$ only onshore movement of sediment is possible because, for grains smaller than D_{crit}, $F_f<F_g$. When $D_{crit}>D_e$ both net offshore and onshore transport may occur.

On a seaward sloping surface of constant inclination D_e diminishes steadily in deeper water as the forces of mass transport diminish. In the study area it is apparent that a reversal in that trend occurs between 45 and 60 feet. The reversal is related to the abrupt change in slope at the base of the shoreface. The slight seaward slope of the offshore sand plain reduces F_g so that the small mass transport velocities experienced at those depths are sufficient to cause equilibrium oscillation of relatively large grains. At slightly shallower depths, the inclination is greater and F_g is correspondingly larger so that D_e is less. Coastward of the change in slope mass transport velocities rapidly increase with shoaling water and the equilibrium diameter increases.

Several generalizations can be made from these graphs. 1) Near the coast (in water depth less than 45 feet) D_e increases rapidly in a shoreward direction because of the large component of forward motion imparted by wave transformation; near the breakers all but the largest grains are carried shoreward. 2) On the gently sloping offshore sand plain D_e is always greater than D_{crit} when wave energy is sufficient to affect the bottom sediments, so that net transport in depths greater than 60 feet is coastward. 3) Shoreward of the 60 foot isobath grains of a size such that $D_{crit}>D>D_e$ first begin to move offshore in response to dominant gravitational forces. They continue to be transported offshore until $U_{max}<U_{crit}$ for that grain size. However, for certain conditions of wave energy and grain size, equilibrium conditions are reached on the lower shoreface as slope diminishes and $F_f=F_g$. 4) Concurrently, grains are being transported coastward from the offshore sand plain and may become part of the equilibrium grain population on the lower shoreface or, if sufficiently fine that $F_f<<F_g$, they may be transported to the breakers. 5) With increasing wave period and height D_e increases at all depths, reflecting the increase in mass transport velocity.

The concept of the equilibrium beach (Ippen, 1966) presumes that at any location on the subaqueous beach face, grain size and slope are so adjusted to incident wave energy that null conditions are satisfied. The D_e curves presented in figures 27-30 can be used to predict trends in grain size which satisfy requirements for equilibrium at any depth. The following inferences can be drawn from those graphs regarding theoretical sediment distribution. For the present slope the offshore sand plain will have no equilibrium grain size because, for most waves, $D_{crit}<D_e$. The surface is a degrading surface with all net sediment movement

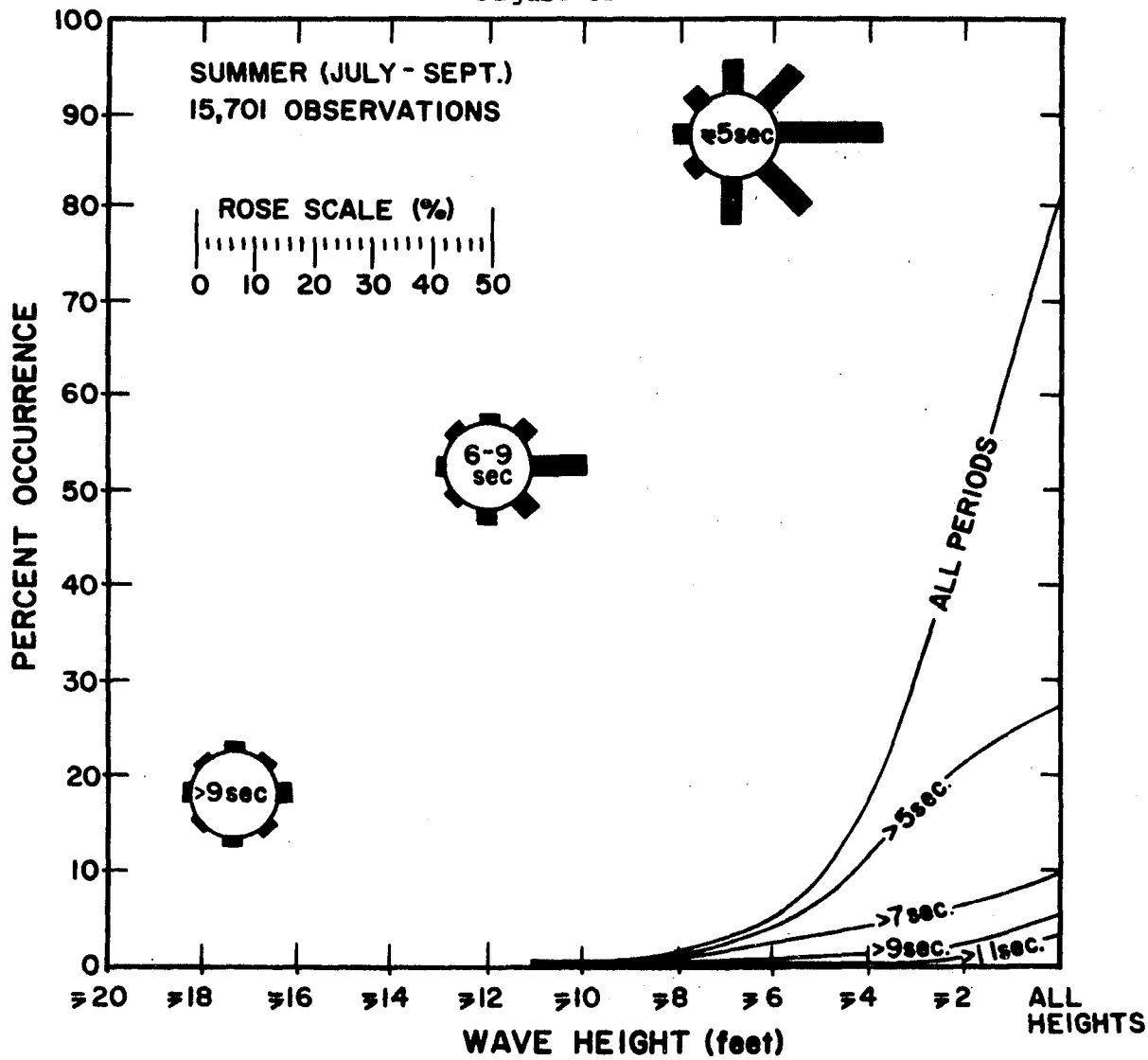
coastward; the remaining sediment will assume the character of a lag deposit with texture determined by the initial grain size distribution and the frequency and magnitude of wave disturbance. Except for the finest material, grains derived from winnowing of sediments of the offshore sand plain are deposited at their equilibrium position on the lower shoreface. A grain size minimum is predicted at the base of the upper shoreface at 45 feet where the slope begins to diminish. The sands of the upper shoreface increase in grain size coastward in equilibrium with incident wave energy.

Sediment which accumulates in equilibrium with incident wave energy spectrum will experience no net transport when shoreward and seaward motion is averaged over a sufficient length of time. D_e for any location or depth will be that grain size for which time spent in coastward transport is equalled by time spent in seaward transport assuming that both processes are of equal efficiency. The theoretical D_e for any depth in the research area can be approximated from a consideration of wave characteristics in the Gulf of Mexico.

Wave Energy Spectrum

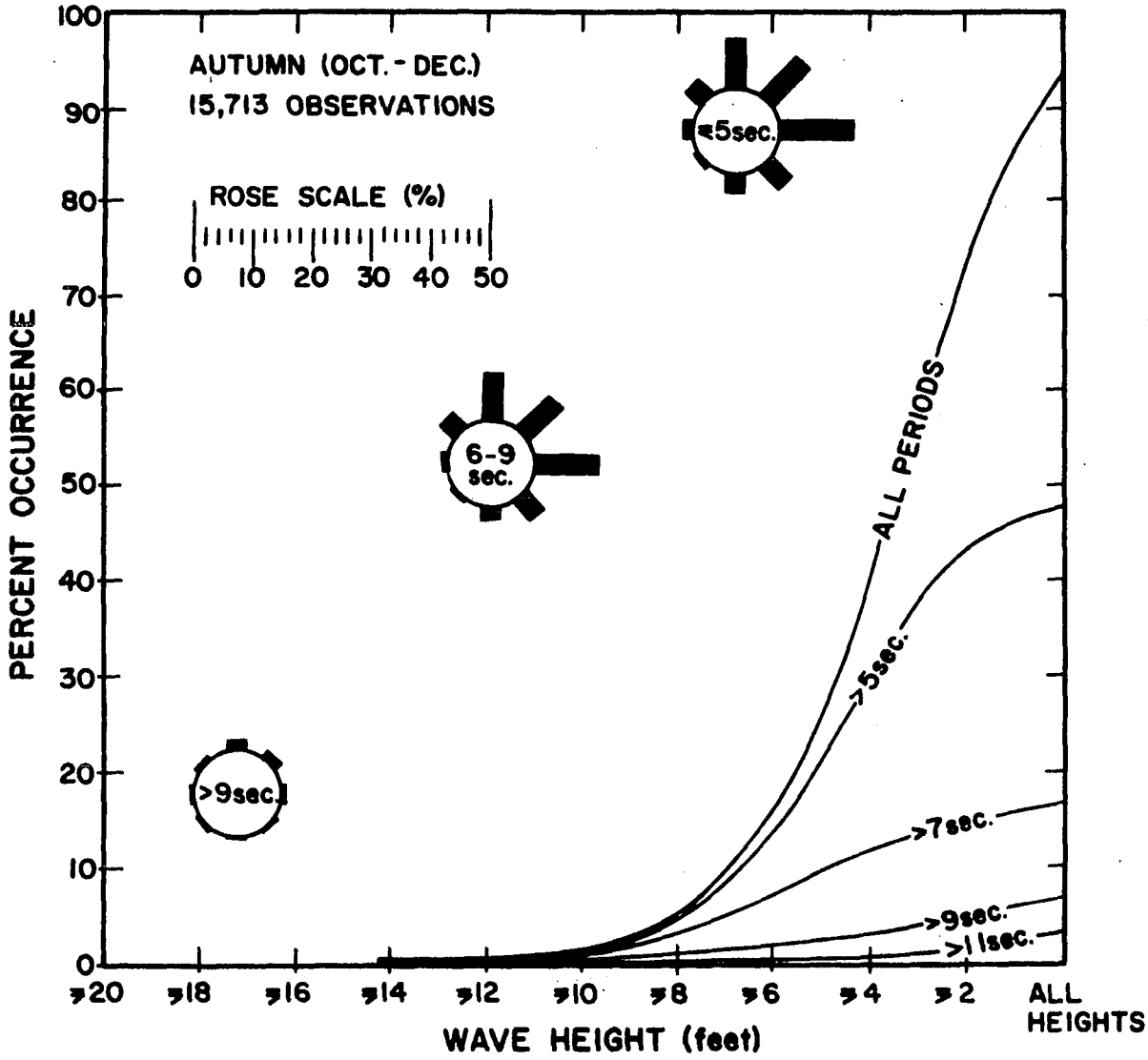
Figures 31-34 present, in graphical form, data from 62,106 visual observations of wave period, height, and direction in the Gulf off the coasts of Mississippi, Alabama, and Florida since 1949. These data were obtained from an unpublished anonymous report by the Climatology Section, Eglin Air Force Base, Florida. The frequency of occurrence of large waves is exaggerated in these graphs relative to their occurrence at the coast because many of the observations were made at considerable distance

Figure 31



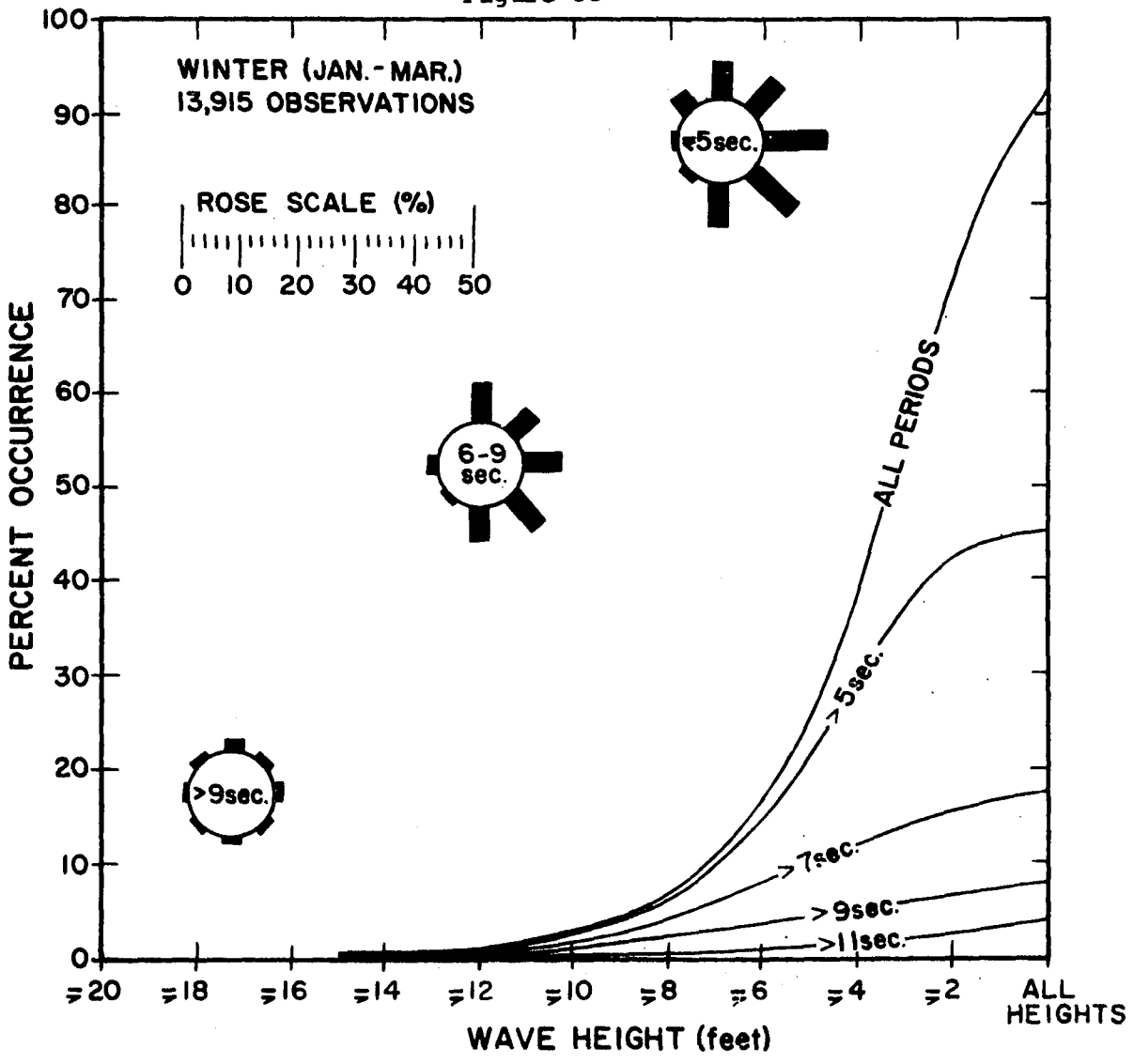
Percent Occurrence of Offshore Wave Heights and Periods - Summer (from unpublished report, Climatology Section, Eglin Air Force Base, Florida). Visual observations since 1949 combined for an area of the Gulf of Mexico north of 25° N. Lat. and lying between 85° and 90° W. Long. Direction of wave advance is indicated by rose diagrams for waves of periods shown.

Figure 32



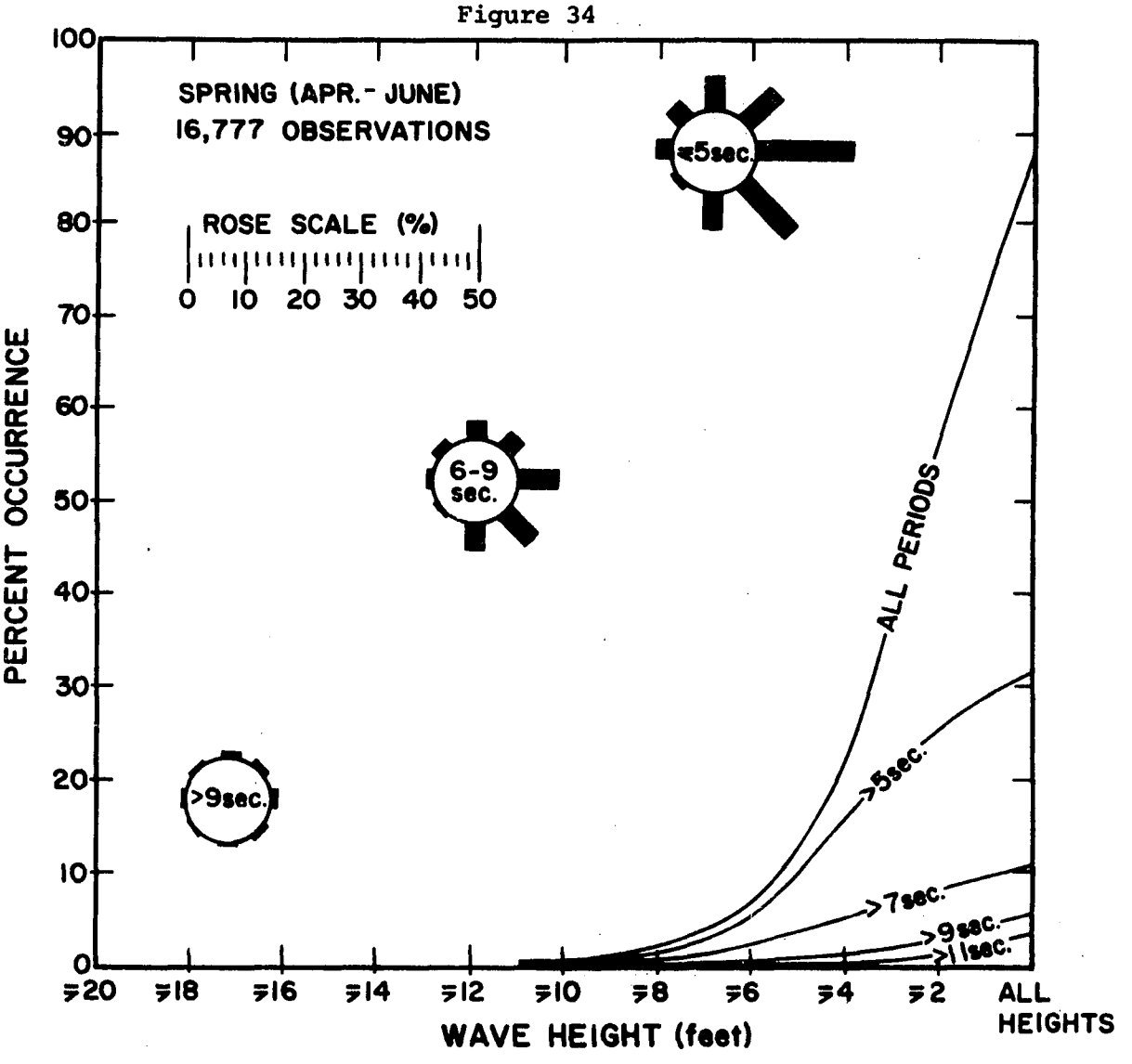
Percent Occurrence of Offshore Wave Heights and Periods - Autumn (from unpublished report, Climatology Section, Eglin Air Force Base, Florida). Visual observations since 1949 combined for an area of the Gulf of Mexico north of 25° N. Lat. and lying between 85° and 90° W. Long. Direction of wave advance is indicated by rose diagrams for waves of periods shown.

Figure 33



Percent Occurrence of Offshore Wave Heights and Periods - Winter (from unpublished report, Climatology Section, Eglin Air Force Base, Florida). Visual observations since 1949 combined for an area of the Gulf of Mexico north of 25° N. Lat. and lying between 85° and 90° W. Long. Direction of wave advance indicated by rose diagrams for waves of periods shown.

Figure 34



Percent Occurrence of Offshore Wave Heights and Periods - Spring (from unpublished report, Climatology Section, Eglin Air Force Base, Florida). Visual observations since 1949 combined for an area of the Gulf of Mexico north of 25° N. Lat. and lying between 85° and 90° W. Long. Direction of wave advance indicated by rose diagrams for waves of periods shown.

from the coast. The large percentage of waves advancing from the north, northeast, and northwest must be discounted at the research area since no fetch exists there for the generation of such waves. Nevertheless, these data will be used as a first approximation.

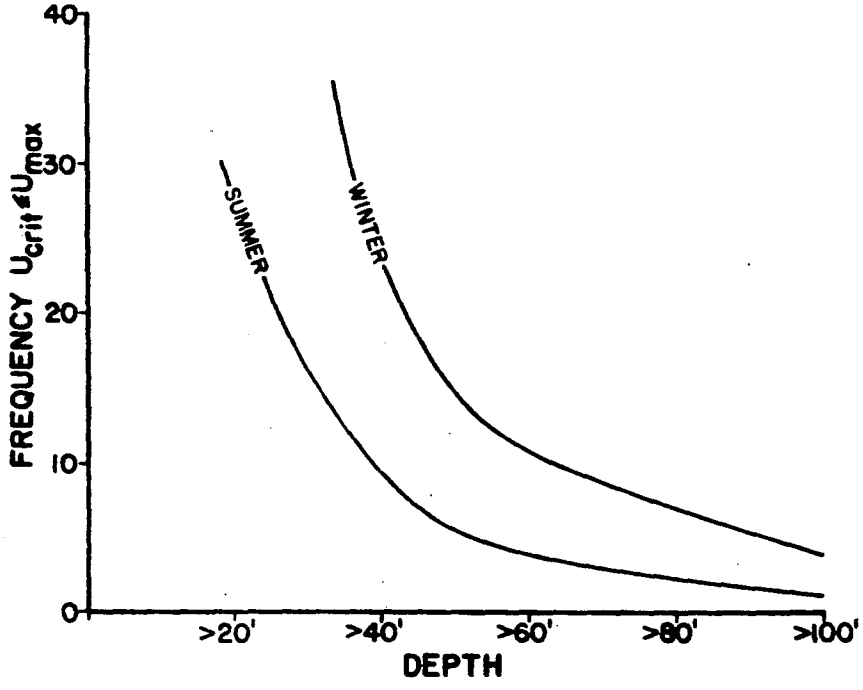
The percentage of time that U_{max} is sufficient to disturb the bottom sediments in the study area can be estimated from wave data in combination with figures 22-25. Figure 35 presents cumulative frequency curves for disturbance by summer and winter wave regimes. It is probable that the summer curve is more representative of average conditions for reasons given above. Although the frequency of disturbance decreases rapidly with depth, it is surprising that at depths greater than 60 feet sediment is in motion 4 percent of the time.

Calculated Equilibrium Grain Size Profile

The calculated equilibrium grain size profile in the research area can be determined by the construction of graphs such as figure 35. Three regions are identified for any grain size and water depth under varying conditions of wave height and period. The region of no transport occurs where waves are of insufficient energy to disturb the sediment of the grain size in question. This region is separated from regions of motion by a line which represents the critical conditions of wave height and period necessary to cause incipient motion. The region of offshore net transport is separated from the region of onshore transport by the equilibrium wave conditions at that depth extracted from figures 27-30.

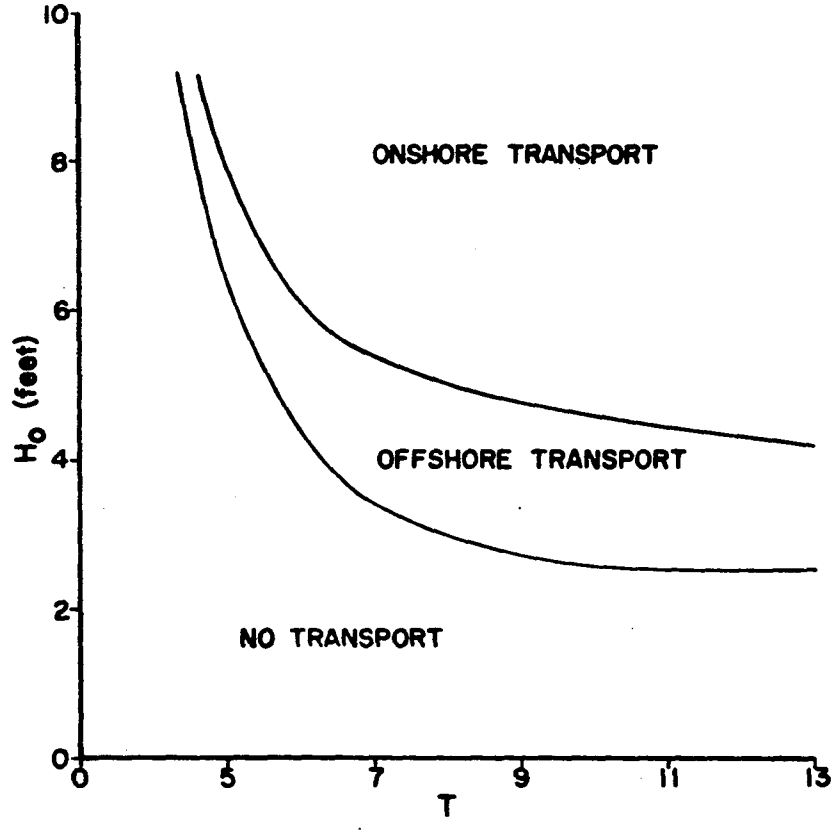
Several generalizations can be made concerning the movement of sediment. At all depths studied, no movement of sediment occurs under

Figure 35



Frequency of Bottom Disturbance Calculated from the Summer and Winter Offshore Wave Regimes.

Figure 36



Transport Direction of Quartz Grains .35mm in Diameter at a Water Depth of 45 Feet Under Conditions of Wave Height (H_o) and Period (T).

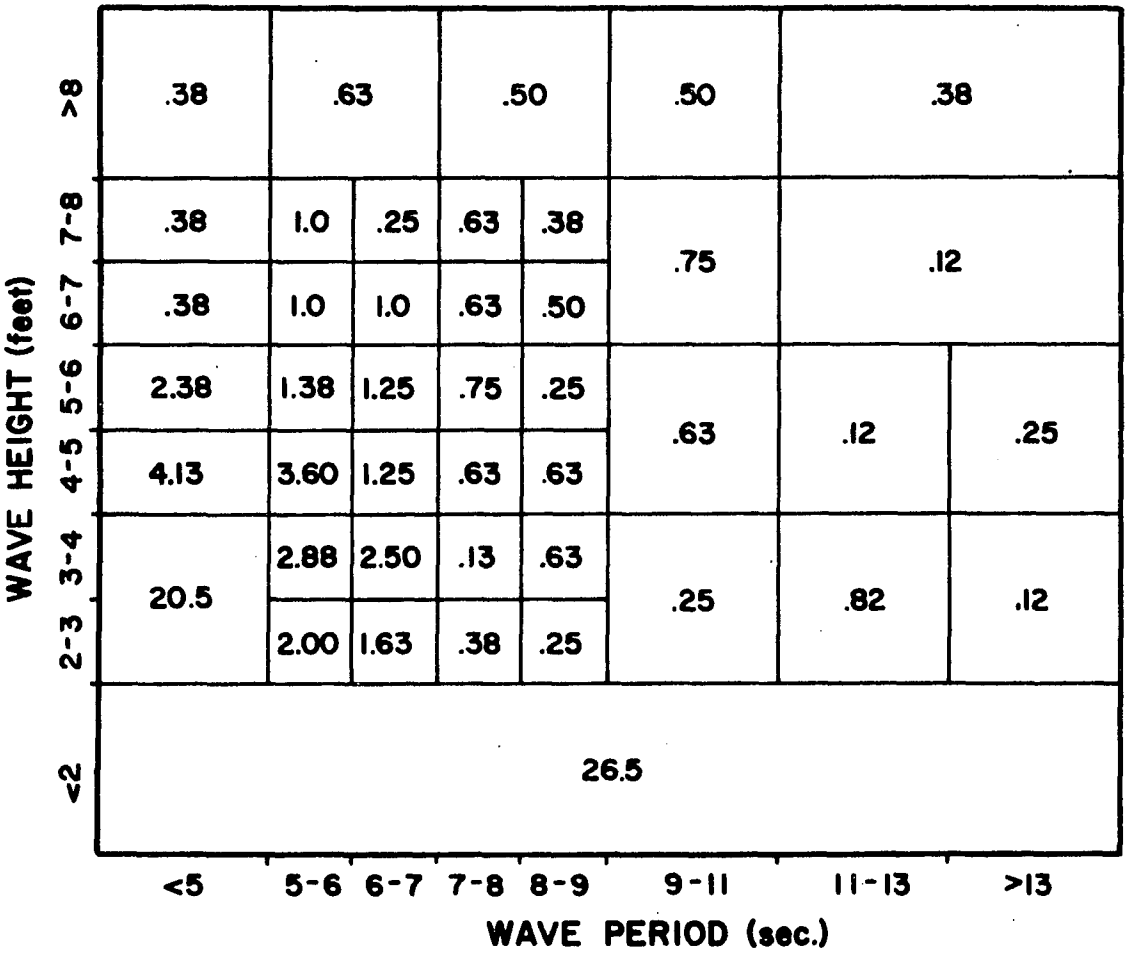
low energy wave conditions. Moderate energy levels favor offshore sediment transport while high energy waves produce net onshore movement of sediment.

The frequency of occurrence of waves of selected heights and periods can be calculated from wave data described previously. Average frequencies were prepared on an overlay (Figure 37) which, when applied to graphs such as figure 35, permits the determination of the equilibrium grain size for a given water depth such that the frequency of occurrence of waves causing onshore transport was equaled by the frequency of waves causing offshore transport. The calculated or theoretical grain size profile for the research area is shown in Figure 38. Predicted grain sizes fall in the medium to very coarse sand range. The equilibrium grain size decreases seaward from coarse sand at 25 feet to medium sand at 40 to 45 feet. It then abruptly increases to very coarse sand at 55 feet at the base of the shoreface. No equilibrium size is determined at depths greater than 60 feet since net onshore sediment movement predominates.

Discussion

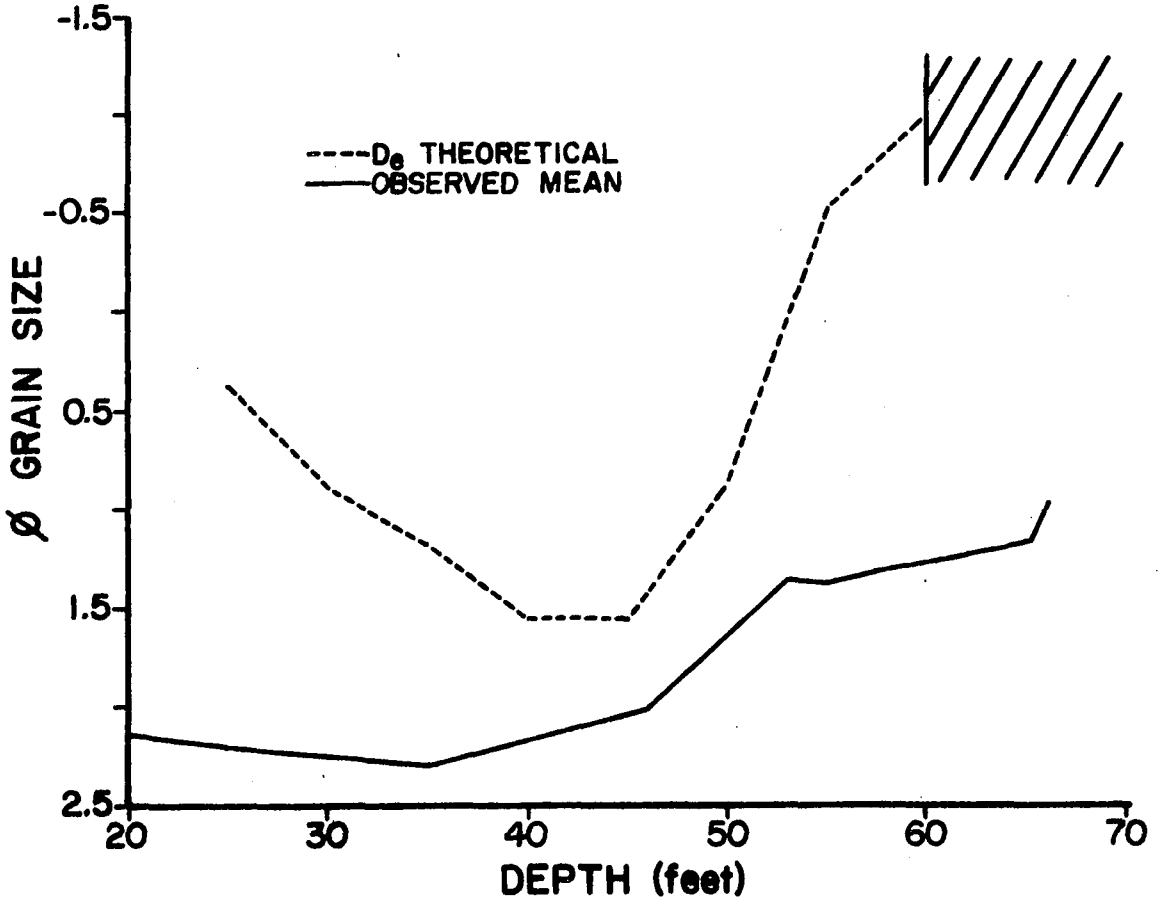
The theoretical grain size profile and the observed profile of mean grain size on line L2 show striking similarities (Figure 38). Although the calculated D_e is always coarser than the corresponding observed mean grain size the trends are essentially the same. This similarity is remarkable and suggests that the observed grain size distributions in the study area are in at least partial adjustment to conditions of slope and incident wave energy.

Figure 37



Mean Relative Frequency of Waves of Given Height and Period. Based on visual observations of wave conditions off the coasts of Alabama, Mississippi, and western Florida (unpublished report, Climatology Section, Eglin Air Force Base, Florida).

Figure 38



Curves of Calculated or Theoretical Equilibrium Grain Diameter (D_e) and Observed Mean Grain Size on Line L2.

Several explanations can be offered for the difference in calculated and observed grain size. 1) Ippen (1966, p. 454) speculated that mass transport velocities predicted by theory may be larger than those experienced on the sea floor as a considerable reduction in velocity is caused by the presence of ripples and other bed-forms. 2) The frequency of occurrence of large waves is probably over estimated in the data used to calculated D_e. 3) The critical erosion velocity of Sundborg (1956) may be higher than actually required to disturb the bottom sediment. Shields (1936) has shown that bed-forms such as ripples lower the critical erosion velocity considerably. If a correction for these three effects is made, D_e is reduced and the theoretical and observed grain size profiles show closer agreement.

Processes of Sedimentation

It therefore seems plausible that processes of bed load transport are active at all depths in the research area. However, these mechanisms become less efficient in deep water where bottom disturbance is infrequent. The general texture of the deeper water, medium- and coarse-grained sands is probably relict. The effect of present bed load transport, as predicted by theory, is to modify and reinforce the trend of seaward coarsening established by the Early Holocene depositional history. The assertion that transport mechanisms active today are of secondary importance is supported by the observation that modal class of the terrigenous medium sands (population 2) is constant in water depths of 50 to 65 feet. If population 2 was a result of equilibrium deposition, under the present conditions of depth and slope, a range of modal sizes would be expected which reflects equilibrium requirements at each depth.

The deeper sands are therefore palimpsest sediments by the definition of Swift et al. (1971).

The zones of mixing between populations 1, 2, and 3, identified by bimodal grain size frequency distributions, can be explained by bed load transport processes. A review of Sundborg's (1956) competency curves reveals that for fine to coarse sand very little difference exists in the velocity required for initial motion. Where motion is infrequent or episodic, as on the lower shoreface and offshore sand plain, it may be possible for sediment consisting of that range in grain size to be transported as a unit such that the original texture is not significantly altered by sorting processes during transportation. Only when disturbance is fairly constant, as on the upper shoreface, do subtle variations in average fluid forces cause adjustment of texture.

The equilibrium model developed by Ippen and Eagleson (1955) applies only to bed load transport systems. The relative efficiency of the winnowing of fines in a wave-dominated regime is to a large extent a function of suspended sediment supply (McCave, 1971). If the supply of suspended material exceeds the ability of the energy regime to remove it, fine sediment will be deposited regardless of equilibrium conditions. At the study area, the amount of suspended sediment is very low so that even with infrequent disturbance the accumulation of fines is of negligible influence on texture. During calm weather, thin layers of organic clay are sometimes found draped over large-scale ripples in coarse sand. These fines are apparently resuspended during storms and removed. Hyne and Goodell (1967) also referred to thin silt and clay laminae, overlying coarse sands, which were no doubt similar transitory features.

Disturbance by large storm waves results in net shoreward bed load

transport at all depths in the research area. Pilkey and Field (1972) demonstrated onshore movement of sediment across the Atlantic shelf by the occurrence of relict ooliths and phosphate grains in modern beaches. Coarser material derived from the offshore sand plain is deposited at the base of the shoreface while finer sediment becomes part of the general coastward moving bed load. During storms, coastward moving sediment is not deposited on the beach but enters the longshore drift system. Fine sediment is maintained in suspension by turbulence and returned offshore by rip currents, mid-depth return flow (Inman, 1963; Smith and Hopkins, 1972), or the process of trough passing (see Ippen, 1966).

The lime grainstone outcrop constitutes a point source of fine and very coarse sand on the offshore sand plain. Fine sand is carried coastward by wave drift but is impeded in this process by other factors. These are the cohesiveness of this sediment resulting from its fine grain size, the presence of admixed organics, and the local occurrence of polychaete worm tubes which bind the sediment. These factors operate to slow or prevent the reentrainment of fine sand once deposited. However, the accumulation is unstable and temporary as indicated by the pockets of erosion and winnowing referred to previously. Very coarse grains derived from the limestone probably cannot be moved under most conditions of U_{max} and remain as lag.

Dispersal of Coarse Biogenic Material

Little quantitative work has been done concerning the movement of coarse shell material by currents. The complex shapes of fragments and whole shells inhibit the development of a rigorous general expression of the relationship between fluid forces and incipient motion. Nevertheless, certain semiquantitative generalizations can be made based on experimental

investigations by Menard and Boucot (1951) and Johnson (1957).

Menard and Boucot found that initial motion of whole shells and single valves depends on their effective density, that is, their immersed weight per unit volume. Because of the low effective density of such material the critical current velocity required to initiate movement was .1 of that required to move pebbles of the same nominal diameter. For valves 1 to 4cm in length critical velocities ranged from 8 to 18cm/sec. Larger shells and valves tend to be buried in the substrate by scouring and filling as the current velocity is increased. The critical factor which determines whether transport or burial will occur is the relative ease of movement of substrate and shell. If the substrate begins to move under certain velocity conditions before the shells, burial results; if shells are small enough (light enough) so that their critical velocity is lower than the substrate, they are transported.

Johnson studied the burial process in greater detail. His findings confirmed those of Menard and Boucot. In addition, he concluded that orientation is important relative to transport versus burial. Valves oriented concave up tend to be transported while valves oriented convex up are hydrodynamically stable and are buried. Velocities required to initiate movement of single valves oriented concave up were considerably higher than those found by Menard and Boucot; velocities of 28 to 33 cm/sec transported *Clinocardium nuttalli* valves ranging in length from 2.46 to 4.55cm. When valves were concave down very high velocities were necessary to cause transport rather than burial.

In the research area oscillatory velocities capable of moving even large shells and fragments are infrequently attained as is evident from previous discussion. Smaller shells and fragments begin oscillating

before the medium or coarse sand substrate in deeper water. Sternberg (1967) noted that increased current velocities in a tidal channel resulted first in transport of shell fragments from ripple trough to trough. The concentration of shell material in the troughs of large-scale ripples on the lower shoreface and offshore sand plain suggests that sediment movement is initiated in a similar manner in the study area. The movement of biogenic debris at lower velocities than the substrate reflects not only the low effective density and shape of those particles but also the fact that shell material, because of its relatively large size, projects through the boundary layer into higher velocity regions.

Large shells may begin to oscillate but if they come to rest concave down they can be entrained again only at unrealistically high current velocities. The observations of Clifton (1971) and Emery (1968b) have shown that bivalve shells tend to assume a concave up position in quiet or deep water due to the activities of scavengers and burrowers. Large valves which come to rest concave down during oscillatory motion may then be turned concave up by biologic activity during periods of low energy and thus again be subject to transport.

From theoretical and experimental considerations we may predict that:

1) On the offshore sand plain, oscillating shell material of all sizes experiences only net coastward forces of mass transport,

2) During severe weather a general onshore movement of biogenic debris occurs at all depths since $F_f > F_g$. Smaller fragments and valves are carried shoreward with greater efficiency than larger debris not only because of the difference between fluid and gravitational forces but also because of the tendency of large valves to be buried *in situ*,

3) At the same time, shallow water shells may be suspended in the breaker zone and carried offshore by compensatory currents. Under conditions of moderate wave energy, bed load transport mechanisms may also contribute upper shoreface shells to the lower shoreface. The shoreface therefore becomes a zone of mixing for shallow and deep water biogenic material,

4) The most heterogeneous mixture of skeletal debris should occur at the base of the shoreface where coarse material derived from both the offshore sand plain and the shoreface may accumulate,

5) Bed load transport cannot account for the presence of shallow water shells on the offshore sand plain since mass transport is always landward there.

It has been demonstrated that the size frequency distribution of biogenic material reflects the same processes of sorting and transport which account for the distribution of terrigenous sediments. Some predictions concerning the distribution of coarse biogenic material have been made above, based on concepts developed in the previous discussion. We may now turn to the investigation of the relationship between the thanatocoenosis and the biocoenosis to determine if the predicted directions of transport and distribution accord with reality.

TABLE 1

List of Abbreviations

α	= angle of bed to the horizontal
υ	= kinematic viscosity
k	= wave number = $2\pi/L$
S_s	= specific gravity of sediment
S_f	= specific gravity of fluid
H	= wave height
L	= wave length
T	= wave period
h	= water depth
sinh	= hyperbolic sine
g	= acceleration of gravity
U_{max}	= maximum orbital velocity
U_{crit}	= critical erosion velocity
D_{crit}	= critical grain diameter
D_e	= equilibrium diameter
o	= subscript refers to wave properties in deep water

BIOTA

Methods and Procedures

Collection

Several different types of samples were collected from which the distribution and composition of the thanatocoenosis and biocoenosis were determined. These include: 1) semiquantitative, 2) qualitative, 3) bulk sediment, and 4) rock samples.

Four semiquantitative samples were taken at each location along lines L1 and L2, two at locations on line RL1. A randomization scheme was at first employed to reduce within-location operator bias but the procedure was abandoned when it became apparent that any sample was essentially random on the monotonous sand plain unless considerable effort was made to collect in a nonrandom fashion. Each sample consisted of the residue from about 1.5 cubic feet of sediment passed through an 8 mesh (2.38mm) box sieve on the sea floor. Sediment was sampled to an average depth of 1 foot. The volume of sediment sieved at each location was consistent on the sand plain, but adjacent to the limestone outcrop the total sampled volume was somewhat smaller due to the coarse nature of the debris and the correspondingly large residues. The sieved residues, containing both living and dead biogenic material, were placed in labeled cloth bags and taken to the surface.

At each location and particularly in the area of outcrop qualitative collections of living biota and biogenic remains were made. Representative specimens of most contributory or abundant species of macroinvertebrate were located by inspection. On the sand plain, infaunal

mollusks were sparse and collected with difficulty by digging over a wide area. Polychaetes and other small infaunal groups were collected with a 20 mesh (.84mm) screen. The epifaunal rock substrate community was sampled by careful inspection of rock surfaces and overturned blocks. Only those groups which contribute significant biogenic skeletal remains or are conspicuous or abundant were collected. A thorough inventory of all components of this community is beyond the scope of this report.

Two bulk sediment samples, collected at locations described previously, provided data on species composition of the microfauna as well as sediment texture. Some aspects of the size distribution of carbonate skeletal material in these samples have already been discussed.

Blocks of limestone were collected for later investigation of boring or cryptic species.

In addition to the above samples, a census of living macroinvertebrates was conducted at alternate locations on lines L1 and L2 to provide additional data on the density and distribution of some of the more important contributors of biogenic material. An area of approximately 100 square feet was outlined on the sea floor, and the number of individuals of each species was determined by carefully digging by hand through the upper six inches of sediment.

Processing

Living and articulated specimens were separated from shell debris of the semiquantitative samples and preserved in 70 percent ethynol. The species composition of this material was later tabulated (Tables 2, 4, and 8). Dead biogenic material was air dried and sieved by hand through five sieves with openings of 64.0, 15.85, 7.93, 2.38, and 1.65mm to facilitate

counting and to provide a rough estimate of size distribution. Each mesh fraction was weighed, and the species and individuals of each species were counted and tabulated.

Identifiable mollusks were counted and classified according to 4 preservation categories and 3 breakage classes yielding 12 categories in all. Preservation categories were 1) fresh -- surfaces appearing perfect and uncorroded, 2) slightly corraded -- surfaces somewhat altered in appearance with a slight degree of chalkiness and lack of luster, 3) moderately corraded -- surfaces entirely or almost entirely lacking in luster and chalky but with ornamentation and hinge structure well preserved, 4) severely corraded -- surfaces pitted and corroded, ornamentation subdued or removed, hinge structure obscure. The term "corraded" refers to surface condition without specification of corrosion or abrasion as the active agency. Within each preservation category three breakage classes were recognized as follows: 1) unbroken -- essentially whole, allowing for chips along the commissure in the case of bivalves or around the aperture of gastropods, 2) broken -- missing a significant portion of the valve or spire, but with the cardinal hinge area visible or most of the columella present, 3) fragment -- cardinal area or columella absent, identifiable principally by ornamentation. Whole and broken valves were determined as right or left as well so that each identifiable valve was classified a total of 3 ways.

Biogenic material other than mollusks was identified and counted without reference to preservation. Unidentifiable bivalve and gastropod fragments were included in this group.

All molluscan specimens larger than 7.93mm were counted and classified according to the above system. However, the amount of biogenic

material 2.38 to 7.93mm in size was so great that, in most cases, only a subsample of that size range could reasonably be examined in detail. The number of specimens included in the counted subsample varied from about 250 to 600 total for all categories of identifiable molluscan remains. A further split of the counted material was made to obtain a sub-subsample of other biogenic fragments which were identified and counted to 300 specimens (Appendix E). The weights of subsamples and sub-subsamples were recorded and used to correct counts to total sample size. The data were tabulated on code sheets and punched on computer cards for subsequent analyses.

Biogenic material finer than 2.38mm was not represented quantitatively in the samples as this material was finer than the mesh of the sampling screen. However, a considerable amount of finer material was retained on the screen and provided at least a qualitative estimate of the composition of smaller biogenic remains.

Analysis

1. Data derived from counts of biogenic material from semiquantitative samples were converted to relative frequencies of occurrence for each bivalve species within selected preservation-breakage categories. Relative frequency tables, by species and sample number, were generated by computer. Raw frequency counts are stored on punched cards in the Museum of the Department of Geoscience, Louisiana State University. The data can be assessed and relative frequency tables printed utilizing the programs presented in Appendix K. In this analysis, left and right valves were pooled within preservation-breakage categories to provide the total number of valves of each species in each category, excluding

fragments. Identifiable bivalve fragments were treated separately and the relative frequencies tabulated.

2. The relative frequencies of total bivalves (unbroken and broken) among the four preservation categories were determined for each sample from the relative frequency tables described above.

3. The relative frequencies of bivalve fragments as well as all biogenic grain types including bivalves (unbroken and broken) were determined for each sample (Appendix E).

4. Counts of left and right valves were made for common bivalves in samples on line L1 (Appendix G); total numbers of right and left valves for all samples in the study area were tabulated (Appendix G).

Statistical analyses of relative frequencies and other data were carried out only on selected variables and when interpretation was ambiguous. Five types of analyses were performed: 1) analysis of variance, 2) correlation, 3) non-parametric chi-square, 4) paired t, and 5) Fisher's exact probability.

The relative frequency distribution of selected bivalve species and other biogenic grain types was evaluated on lines L1 and L2 with an analysis of variance in the form of a completely randomized design with a factorial arrangement of treatments. Treatments were traverse line-distance from shore (location) combinations where corresponding locations along the two traverse lines were equidistant, or approximately so, from the coast. The F test was used to evaluate location and traverse line differences in average relative frequency as well as the interaction. Sources of variation, degrees of freedom, mean squares, and F statistics are tabulated in Appendix H. The distribution of total living bivalves by location was also assessed as above.

Linear relationships between grain size, water depth, percent bivalve fragments, percent well preserved shells, and percent biogenic material 2.38 to 7.93mm in size were investigated with analyses of correlation. The F test was used to detect significant positive or negative linear relationships between these variables (Appendix I). The degree of relationship between number of living bivalves and distance from the coast was evaluated at locations on line L1 with a correlation analysis.

Proportions of right and left valves of selected bivalve species for all semiquantitative samples were evaluated with a chi-square for goodness-of-fit test. The chi-square statistic evaluated the consistency of relative proportions of right and left valves among samples. The chi-square was also used to test for recurrent associations of species pairs in the thanatocoenosis in the manner described by Johnson (1962). Two by two contingency tables were prepared for each species pair including the number of samples of joint occurrence, the number of samples of joint absence, and the number of samples in which each species occurs separately (Appendix F). The chi-square statistic tests the hypothesis of independent distributions against the alternate hypothesis of significant association. Johnson (1962) recommended that the level of significance be selected by trial-and-error such that most of the species are bonded to one or more species; that procedure was followed here.

The paired t-test was utilized to determine if the average number per sample of right and left valves for selected species differ as well as whether the average total numbers of right and left valves in all samples differ.

Occurrence, by location, of living bivalves and articulated shells

were compared with the Fisher's exact probability test. Small numbers of occurrences made the application of the chi-square test inappropriate. Two by two contingency tables were constructed for each commonly or consistently occurring species (Appendix J). Tables included the number of joint occurrences of articulated and living specimens, the number of joing absences, and the number of locations at which articulated or live specimens occurred separately. A significant test statistic led to rejection of the hypothesis of independent distribution and acceptance of the alternate hypothesis of significant association in the occurrence of living and articulated specimens.

For a complete discussion of the statistical tests and procedures described above see Snedecor and Cochran (1967), Siegel (1956), and Johnson (1962).

Macrobiota

The term "macrobiota" in this report refers to organisms and their remains or shells which will not pass through a 1mm screen. Because a sieve size of 2.38mm was employed to collect most of the sample material upon which the following discussion is based the macrobiota is not fully represented. Many juvenile shells or smaller species may have been overlooked in the analysis. However, in order to achieve large, statistically valid counts of adult organisms of the more important invertebrate groups, a sacrifice of accuracy in the smaller size range was unavoidable. Warme (1971) in a similar study of the biota of Mugu Lagoon was able to make an important contribution based on macroinvertebrates of 3mm or larger. Since the present study is concerned primarily with the

transport and dispersal of coarse biogenic material it is appropriate that most emphasis be placed on the larger invertebrates.

Faunal Constituents - Sand Bottom

Representatives of all major benthic marine macrobiotic Phyla are found in the research area. Of these, only 6 groups are important contributors of biogenic material or are significant in biologic sediment modification. These are: 1) Mollusca, 2) Echinodermata, 3) Crustacea, 4) Bryozoa, 5) Polychaeta, and 6) Corallinaceae.

In terms of numbers of species, mollusks are the dominant group. The bivalves are represented by 41 families and 114 species, the gastropods by 37 families and 95 species, the scaphopods by 2 families and 3 species, and the amphineurans by one species. The molluscan assemblage is not well represented in the living fauna. Only 49 species were collected alive (34 bivalve, 15 gastropod, 1 scaphopod, and 1 amphineuran species) totaling 287 individuals for all semiquantitative samples.

The Echinodermata are abundantly represented in the living community by 10 species: 4 asteroid, 4 echinoid, and 2 holothurian species. Not included are 3 or 4 rare, unidentified species of ophiuroid.

The Crustacea were not studied in detail, but a diverse assemblage was noted. Fragments of exoskeleton and barnacle plates are minor components of biogenic fragmental debris.

Bryozoa of the sand bottom are represented by 4 species, 3 of which contribute minor debris, in the form of discoid zoaria, to the deeper water sediments. Free-living corallinaceid plants (predominantly of one species of *Neogoniolithon*) are commonly found on the offshore sand plain.

Twenty-five species of polychaete annelids were identified from

the sand substrate. These produce a variety of tubular living and feeding structures which penetrate and modify the surrounding sediment.

Faunal Constituents - Limestone Bottom

The biota of the limestone substrate is diverse and abundant. The dominant groups include: 1) Mollusca, 2) Coelenterata, 3) Porifera, 4) Echinodermata, 5) Bryozoa, 6) Polychaeta. No rigorous quantitative estimate was made regarding the relative abundance of these constituents. Species were identified from qualitative collections.

The mollusks are represented by 12 bivalve species and 7 gastropod species. Coelenterates include a number of unidentified species of anemone, 5 species of scleractinian coral, and 2 common species of alcyonarian. Many species of encrusting sponge are represented in the fauna some of which have been identified at least to genus. The echinoderms comprise 2 species of regular echinoid and an asteroid which preferentially inhabits the rocky substrate. The Bryozoa are represented by 3 species of erect cheilostomatids and at least 15 species of encrusting forms. Many species of serpulid and other polychaetes are associated with the limestone substrate. Collection of these organisms was difficult, and since they do not contribute significant biogenic debris to the sediment, no attempt was made to obtain or identify them.

Of the above groups only the mollusks and scleractinian corals were capable of producing coarse biogenic material. Their identification in the surrounding sediment is important in its implications concerning the degree of effective or net transport from the limestone biotope.

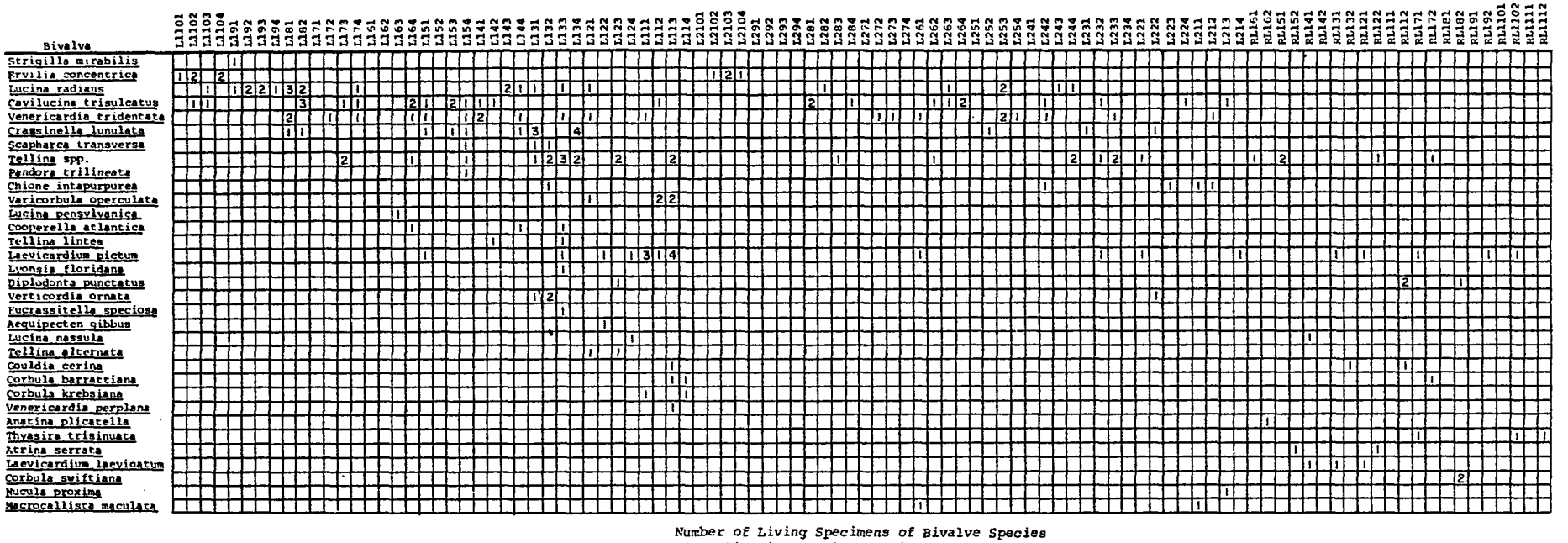
General Life Groups

The invertebrates of the sand substrate are primarily endobiontic in the sense of Schafer (1972); only in deeper water do epibiontic species find suitable substrate for their development. The number of epibiontic species, although small, increases from the coast until, at water depths greater than 60 feet, epibionts contribute significant quantities of biogenic material to the sediment. The endobionts and epibionts have been subdivided into the vagile or mobile species and the conditionally vagile and sedentary forms (Schafer, 1972).

In the research area, conditionally vagile endobionts include most bivalves, scaphopods, and most polychaetes. Also in this group are several species of tube-dwelling and burrowing anemones found in the sand biotope, the common amphioxid *Branchiostoma caribbaeum*, and the enteropneust *Balanoglossus* sp.

Vagile endobionts comprise the sand dollars *Mellita quinquiesperforata*, *Encope michelini*, and *E. aberrans*. These species may remain buried in the sediment or may be observed on the surface covered with only a thin layer of sand. Their grazing trails indicate considerable albeit slow movement in the near-surface sediment. The brissid urchin *Plagiobrissus grandis* burrows beneath the surface as it feeds on organic detritus. Predatory gastropods of the Naticidae, Terebridae, and Olividae are common vagile endobionts. The Olividae may emerge from the sediment possibly to achieve more rapid locomotion. *Holothuria princeps* and another small unidentified holothurian burrow beneath the sediment surface no doubt in accordance with feeding activity. Some crustaceans are also members of this life group of which *Callianassa* is the most conspicuous.

SAMPLES



Number of Living Specimens of Bivalve Species
Semiquantitative Samples on Lines L1, L2, and RL1

Table 2.

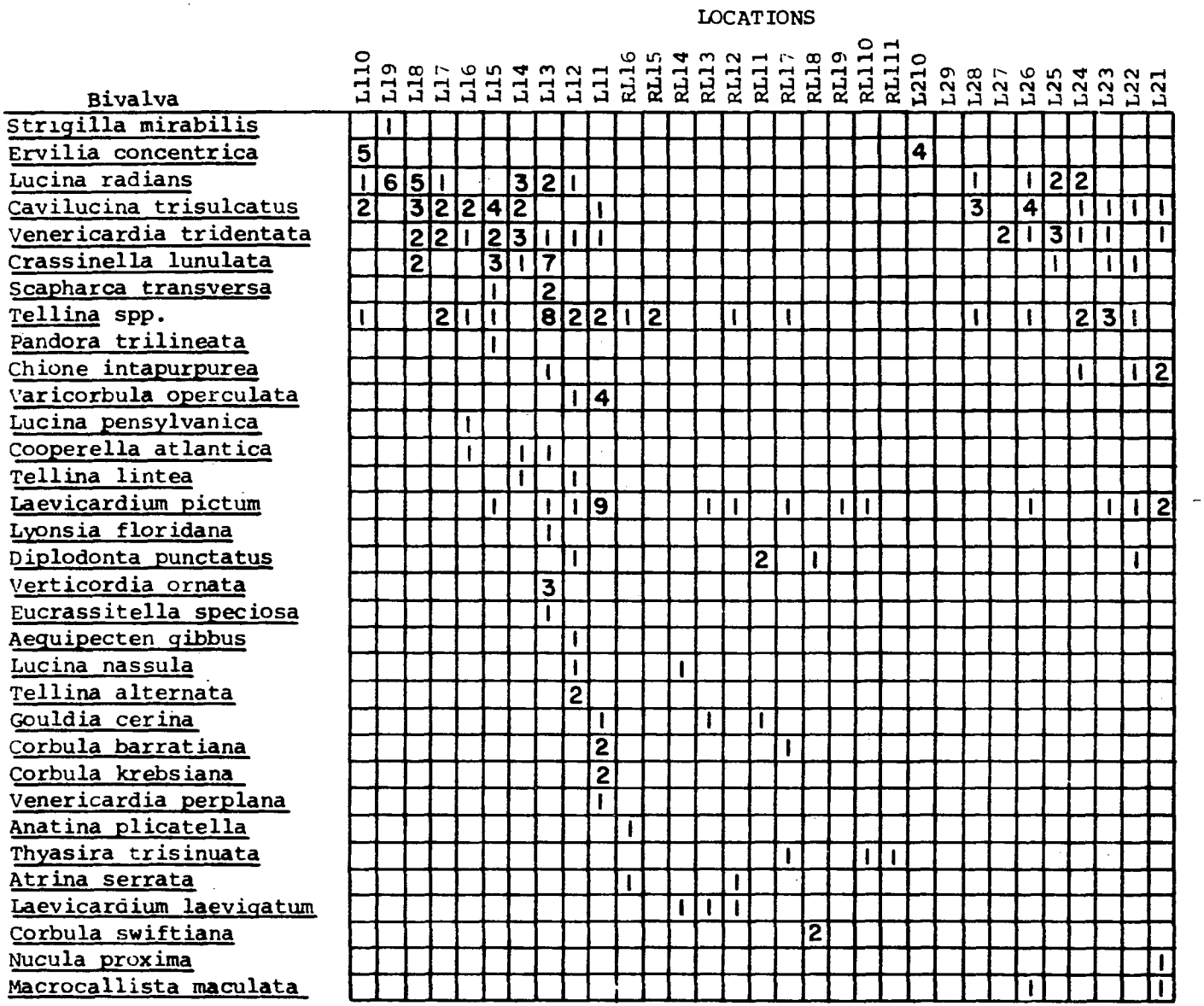


Table 3. Number of Living Specimens of Bivalve Species

Gastropoda	LOCATIONS																													
	L110	L19	L18	L17	L16	L15	L14	L13	L12	L11	RL16	RL15	RL14	RL13	RL12	RL11	RL17	RL18	RL19	RL110	RL111	L210	L29	L28	L27	L26	L25	L24	L23	L22	L21
Olivella mutica	3	1																				2									
Terebra dislocata		1			2																		2								
Natica cf. pusilla	5			3	1	3	2								1	1						4		2	2						
Polinices sp.			1																												
Terebra concava					1																										
Oliva sayana					3			1	1			1	1		1		5		1					1		1		2	1		
Nassarius albus																			1												
Niso interrupta								1																							
Cerodrillia perryae									2																						
Epitonium angulatum											1																				
Polinices lacteus											1			1			1	1	2		1										
Pyrene albella iontha											1																				
Terebra protexta																1															
Polinices duplicatus																	1							1	1				2		
Lobiger pilsbryi									2																						

Table 4. Number of Living Specimens of Gastropod Species

	LOCATIONS									
	L29	L27	L25	L23	L21	L19	L17	L15	L13	L11
Mollusca										
Strigilla mirabilis						X				
Ensis minor						X				
Lucina pensylvanica						X				
Macrocalista nimbosa	1									
Chione intapurpurea		2	3				2	3		
Macrocallista maculata			X	X	X					
Tellina spp.	1									
Phalium granulatum								1		
Terebra dislocata	4	1				4				
Oliva sayana	X	1				1	4			
Olivella mutica	C	C				C	C			
Echinodermata										
Encope spp.	1(A)	1(J)	24(J)	18(J)	5(J)	6(A)	7(A)	2(A)	X	
Plagiobrissus grandis		4(J)	63(J)	8(J)	15(J)					
Luidia clathrata			2	2	1					
Astropectin articulata	4	X	X	1		X	1	4		
Luidia alternata			X	X	X					
Echinaster modestus			1	X	X					
Holothuria princeps				X						

Specimens Recovered in Census of 100ft^2 Areas at Locations on Lines L1 and L2. X - recovered near census area, C - common, not counted, (J) - juvenile, (A) - adult

Table 5

Many species of gastropod found living on sand in the research area are vagile epibionts. Most common are members of the Cassididae, Melongenidae, Conidae, Muricidae, and Fasiolaridae. Other large groups of epibiontic invertebrates are the brachyuran and anomuran crustaceans and the asteroid echinoderms. The brachyurans remain hidden in the sediment awaiting the passage of prey but move rapidly over the sediment surface when disturbed. The asteroids, although commonly observed on the sediment surface, were often found several inches below possibly in search of food (Schafer, 1972). The regular echinoid *Lytechinus variegatus* is seen rarely on the sand substrate in deeper water.

Sessile or sedentary epibionts are found at water depths greater than 40 feet on the sand bottom. At those depths the large tubes of the polychaete *Onuphis magna* project above the sea floor for several inches and support a variety of organisms including bivalves (*Scapharca transversa* and juvenile *Aequipecten gibbus*), the bryozoan *Bugula neritina*, columbellid gastropods, encrusting sponges, and colonial hydozoans. Large shells are a substrate for barnacles, encrusting Bryozoa, calyptraeid gastropods (particularly *Crepidula fornicata*), the bivalves *Anomia simplex*, *Chama congregata*, and *Plicatula gibbosa*, and an amphineuran. In 60 feet or more of water, where bottom disturbance is infrequent, small growths of the scleractinian *Astrangia astreiformis* are found on shell fragments. Also at those water depths living colonies of cupularid Bryozoa are seen resting on the sand. The most common and important epibiont, in terms of contribution of skeletal material, is *Neogoniolithon* sp. which grows free on the sediment in deeper water.

The biota of the limestone substrate is characterized by epibiontic dominance. Although the epibionts are most conspicuous many organisms

inhabit crevices or bore into the substrate. Sessile epibionts include the byssally attached and cemented bivalves of the Arcidae and Chamidae, scleractinians, alcyonarians, sponges, Bryozoa, and a few species of green and brown algae. Vagile epibionts of the limestone substrate are represented by regular echinoids, an asteroid, gastropods of the Trochidae, Ovulidae, and Fissurellidae, and many unidentified crustacean species. Boring or cryptic species are found among the bivalves and polychaetes. The specific representatives of these groups will be the subject of later discussion.

Biotic Density

The sand biotope is inhabited by populations of species whose distribution is a function not only of general ecologic requirements but also of local variation in population density. Quantitative data and direct observation form a basis for the following discussion.

Mollusks - A compilation of species and numbers of individuals of living mollusks found in semiquantitative samples and recorded in census tables (Tables 2-5) indicates a very sparse molluscan assemblage. Samples contain a maximum of 10 living species and from 0 to 12 individuals per sample. Comparable but slightly larger numbers of specimens were reported by Parker (1960) who recorded an average of 5.7 species and 18.8 individuals for van Veen grab samples from the 0-10 fathom inshore zone in the western Gulf of Mexico. Parker's figures include invertebrates 2.38 to 1.0mm in size which were not adequately studied in the present report. Much sparser populations were reported by Parker for continental shelf areas at depths greater than 10 fathoms.

The number of living molluscan species and individuals found in

semiquantitative samples is too low to statistically assess the magnitude or significance of variation among samples or locations and makes any interpretation of population density tenuous. Bivalve species, although most common among the mollusks, are usually represented by only 1 or 2 individuals per sample - a maximum of 4. On a qualitative (presence or absence) basis the occurrence of species is highly variable within locations.

A more comprehensible pattern emerges when the occurrences of species within location are combined (Tables 3 and 4). Of the 34 bivalve and 15 gastropod species represented by living specimens only 12 are at all consistent in their occurrence: *Ervilia concentrica, Lucina radians, Tellina* spp., *Cavilucina trisulcatus, Venericardia tridentata, Crassinella lunulata, Laevicardium pictum, Olivella mutica, Terebra dislocata, Oliva sayana, Polinices lacteus,* and *Natica* cf. *pusilla*. These are diminutive species with adult specimens generally smaller than 8mm with the exception of *Lucina radians* and the common gastropods *Oliva sayana* and *Terebra dislocata*. The consistent occurrence of these more abundant species suggests that their population densities may be assessed with some confidence. The occurrence of living representatives of other molluscan species shows no discernible pattern except a general correlation with depth or distance from shore; sample size or density was clearly insufficient to adequately represent those species. This appears to have been especially true of locations on line RL1 where only 2 samples were collected and where living mollusks were rarely recovered.

Mollusks found living in census areas were few in number and represented only 6 species (Table 5). The diminutive species were probably overlooked but the paucity of living specimens is surprising

even when the inherent inaccuracy of this sampling method is considered. *Chione intapurpurea* is the most commonly occurring of the larger bivalves on the offshore sand plain in accordance with observation. However, other species such as *Laevicardium laevigatum* and *Macrocallista maculata*, frequently observed on the offshore sand plain, were not included in any census area.

The variation in occurrence and abundance of molluscan species among locations and among samples within locations suggests that the distribution of populations of at least the more abundant species is not uniform on the sea floor. However, sample density is not adequate to distinguish between a random pattern and a clumped distribution in the sense of MacFadyen (1963). Aggregation of marine epibenthic and endobenthic populations is quite common. Allee (1934) found a patchy, non-random distribution of marine invertebrates in the same environment and substrate. MacGinitie (1939) emphasized the patchwork arrangement of communities and aggregations of benthic organisms in estuarine and marine environments. In the research area, molluscan aggregations, if they occur, must be rather subtle variations in a general pattern of low population.

Calculated on the basis of an area of 100 square feet, the more abundant molluscan species have densities of 8 to 65. Higher specific and overall densities are developed on line L1 as compared to line L2. Total molluscan population densities are quite variable among locations, ranging from 48 to 225 specimens per 100 square feet for line L1 and from 0 to 72 for line L2. Analyses of variance and correlation indicate that although there are highly significant differences among location in the total number of living mollusks, the differences are not systematic with

depth or distance from the coast.

Echinoderms - Within-habitat distribution patterns of the echinoderms can be assessed by reference to census figures (Table 5) and from observation on the sea floor. The echinoderms show a marked tendency to aggregate in local concentrations. The most striking example of clumping is found in the distribution of *Plagiobrissus grandis*. An extremely dense population of this urchin is found at location L25; at other locations on line L2 populations are much more sparse. Observation indicates that living *P. grandis* is widely distributed for some distance to the east of line L2 and that densities are considerably different from place to place. No living *P. grandis* were encountered in census areas or during sampling or observation on line L1 even though environmental conditions appeared favorable for its development. The populations of *P. grandis* therefore appear to occupy discrete areas of the sea floor within its general habitat.

The sand dollars *Encope michelini* and *E. aberrans* are widely distributed but were not distinguished in the field. Together they exhibit major variations in density along line L2 but are uniform in occurrence on line L1. They, like *Plagiobrissus grandis*, seem to be characteristically clumped but to a lesser degree.

The asteroids *Luidia clathrata, L. alternata,* and *Echinaster modestus* show a tendency to aggregate. This tendency is apparently a response to the availability of food. Wherever concentrations of *Plagiobrissus grandis* were encountered large populations of these predators were also found. The starfish, particularly *L. clathrata,* were observed actively feeding on the juvenile urchins. *Astropecten articulata* is more widely and more uniformly distributed than the other

asteroids.

For comparative purposes, echinoderm population densities can be read directly from Table 5.

Corallinaceae - Five census areas of 10 square feet were examined for living plants of the corallinaceid *Neogoniolithon* sp. in 65 feet of water at the seaward end of line L2. The number of specimens ranged from 15 to 28 with an average of 24. This is equivalent to 240 living plants per 100 square foot area.

Bryozoa - Cupularid bryozoans are estimated at a density of 50 living colonies per 100 square feet in 65 feet of water.

Polychaeta - Polychaete annelids are found in dense populations, some of which are notably aggregated, others of which are rather uniform within substrate and depth-related tolerances of the particular species. Few quantitative data were available for this group. The characteristics of important species will be discussed later.

Comparative Densities

Of those members of the biota which contribute significant biogenic debris to the sediment, the echinoids, because of their large size, dominate the living fauna in terms of skeletal material potentially available from the standing crop and possibly in terms of biomass. An exception to this is found in the surf zone and nearshore bar trough where *Donax variabilis* is abundant. The mollusks are the numerically dominant group except where dense local aggregations of echinoids occur. At water depths greater than 65 feet the density of *Neogoniolithon* may exceed molluscan population density so that at least locally *Neogoniolithon* becomes the numerical dominant.

Polychaetes are by far the most numerous living organisms in the research area except perhaps in the surf zone where mollusks predominate.

Biotic Zonation

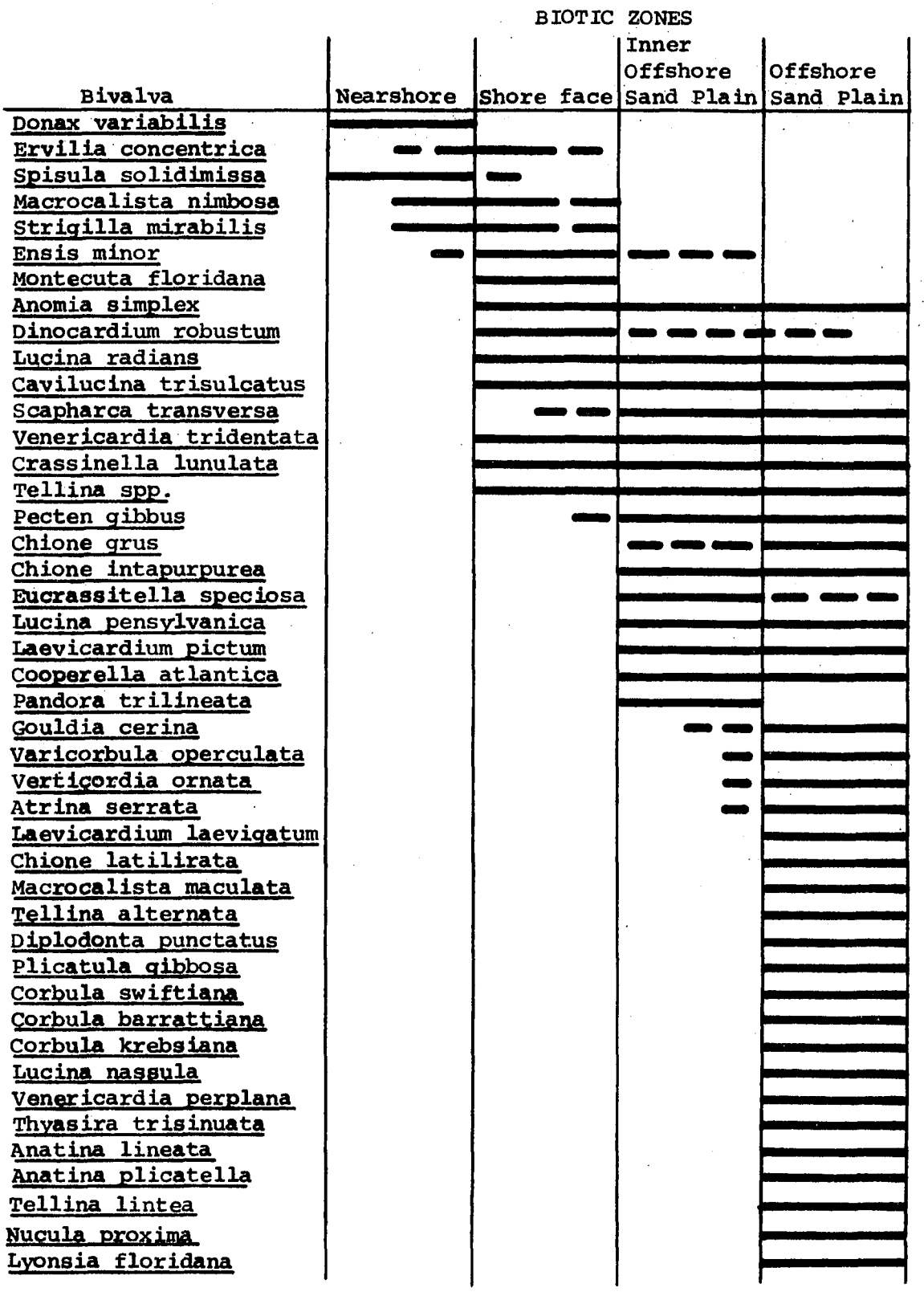
The distribution of benthic macroinvertebrate biota in the research area will be discussed in terms of two major biotopes whose faunal and floral components are almost entirely mutually exclusive: 1) the level bottom, and 2) the limestone bottom.

Level Bottom

Species of the level bottom are generally distributed in zones which parallel the coast and bathymetric contours. Exceptions to this pattern are found where sediment texture is not uniform within a bathymetric zone. The fine sand body found north of the limestone outcrop is an anomalous substrate and supports a distinctive invertebrate assemblage.

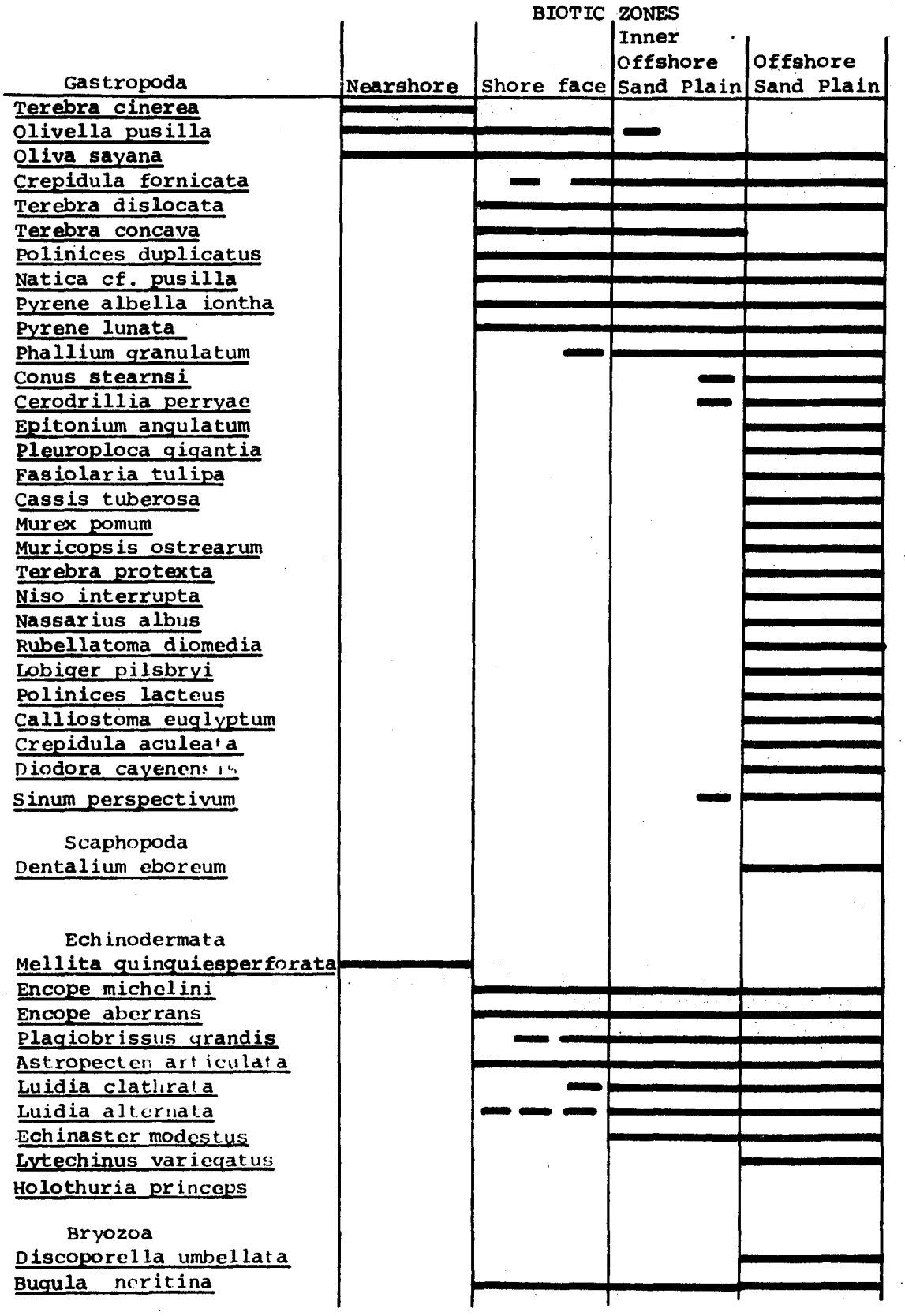
Bathymetric ranges of species of living invertebrates in the study area were determined by a combination of all available data from semi-quantitative and qualitative samples, census tables, and direct observation. The sparse nature and clumped distribution of most of the benthic invertebrates, alluded to previously, make delineation of specific ranges tentative until more complete sampling can be achieved. However, for the more abundant or conspicuous species reasonable accuracy is expected. The bathymetric ranges of all species found alive on the level bottom and which contribute shell material are given in figures 39 and 40. Occurrences of the more important polychaete species are indicated in Table 6 at locations on lines L1, L2, and RL1.

Figure 39



Inferred Bathymetric Ranges of Bivalve Species in the Research Area.

Figure 40



Inferred Bathymetric Ranges of Gastropod, Scaphopod, Echinoderm, and Bryozoan Species in the Research Area.

	LOCATIONS																				
	L11	L12	L13	L14	L15	L16	L17	L18	L19	L21	L22	L23	L24	L25	L26	L27	L28	L29	RL14	RL17	RL18	RL19	RL110
Nephtys picta					X				X														
Arabella iricola	X																						
Ceratonereis irritabilis	X																				X	X	X
Axiothella mucosa	X																						
Onuphis quadricuspis	X																						
Drilonereis sp.	X																						
Chloeia viridis		X								X													
Cistenides gouldii		X						X															
Chaetopterus variopedatus		X																					
Clymenella torquata calida		X																					
Sthenelais articulata		X							X														
Glycera americana		X		X	X														X				
Diopatra cuprea cuprea		X			X		X																
Onuphis eremita oculata		X					X													X	X		X
Loima medusa		X																					
Lepidametria commensalis		X																					
Polyodontes aff. P. maxillosus		X																					
Onuphis magna		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X					
Glycera aff. G. Tenuis					X																		
Neanthes arenaceodonta	X				X																		
Notomastus hemipodus					X																		
Lumbrineris inflata					X				X													X	
Aricidea jeffreysi									X														
Megalomma lobiferum						X		X															

Table 6. Occurrence of Polychaete Species in Collections at Locations on Lines, L1, L2, and RL1

Three biotic zones can be recognized on the level bottom off Moreno Point: 1) Nearshore, 2) Shoreface, 3) Offshore Sand Plain. These zones, although defined on the basis of bathymetry, are recognized by the recurrent associations of species which occur within them.

Nearshore

The Nearshore zone extends from the surf zone to the 20 foot isobath on the upper shoreface. The zone is characterized by locally high densities of *Donax variabilis*, *Mellita quinquiesperforata*, and *Callianassa* spp.

Species	Abundance
Bivalves	
Donax variabilis	locally very abundant
Spisula solidissima	rare
Macrocallista nimbosa	rare
Gastropods	
Oliva sayana	frequent
Terebra cinerea	frequent with *Donax*
Olivella mutica	common
Echinoderms	
Mellita quinquiesperforata	locally abundant
Crustaceans	
Callianassa spp.	abundant
Polychaetes	
Nephtys Picta	abundant

Shoreface

The Shoreface biota is distinct from that of the Nearshore zone by the absence of living *Donax variabilis* and *Mellita quinquiesperforata* and the development of a more diverse although sparse molluscan assemblage which includes as the characteristic species *Strigilla mirabilis* and *Ervilia concentrica*. The appearance of *Encope michelini* and *E. aberrans* in abundance is typical of the Shoreface although they also

occur in deeper water. The polychaetes *Lumbrineris inflata* and *Nephtys picta* and the enteropneust *Balanoglossus* sp. are of extreme importance in terms of sediment modification.

Species	Abundance
Bivalves	
Strigilla mirabilis	rare to frequent
Ervilia concentrica	common
Macrocallista nimbosa	rare
Montecuta floridana	rare
Anomia simplex	rare
Dinocardium robustum	rare
Lucina radians	frequent
Cavilucina trisulcatus	frequent
Venericardia tridentata	frequent
Crassinella lunulata	frequent
**Tellina* spp.	frequent
Gastropods	
Olivella mutica	common
Terebra dislocata	common
Oliva sayana	frequent to common
Natica cf. *N. pusilla*	common
Polynices duplicatus	rare
Terebra concava	rare
Phalium granulatum	rare
Crepidula fornicata	rare
Pyrene spp.	rare
Echinoderms	
Encope michelini	common
Encope aberrans	common
Plagiobrissus grandis	rare
Astropecten articulata	common
Polychaetes	
Lumbrineris inflata	abundant
Nephtys picta	common
Onuphis magna	scattered small aggregations
Megalomma lobiferum	rare
Enteropneusts	
Balanoglossus sp.	abundant
Bryozoa	
Bugula neritina	rare
Lancelets	
Branchiostoma caribbaeum	common

**Tellina* spp. includes a number of small, morphologically similar species.

Offshore Sand Plain

The biota of the Offshore Sand Plain, in the trend of increasing diversity from the coast, is characterized by the addition of many molluscan and echinoderm species. Of the bivalves, *Chione intapurpurea*, *Laevicardium pictum*, *L. laevigatum*, and *Macrocallista maculata* are the most common or conspicuous. The gastropods include a diverse but extremely sparse assemblage of predatory species of which *Busycon contrarium*, *Cassis tuberosa*, *Fasiolaria tulipa*, and *Conus stearnsi* are typical.

The asteroids *Luidia clathrata*, *L. alternata*, and *Echinaster modestus* are found in abundance on the offshore sand plain but only rarely on the lower shoreface. At depths greater than 60 feet the offshore sand plain is characterized by the occurrence of *Neogoniolithon* sp. and the bryozoan *Discoporella umbellata* and other cupularids.

North of the limestone outcrop the fine sand substrate supports a fauna of deposit feeding tellinid bivalves, the scaphopod *Dentalium eboreum*, and a dense assemblage of tubiculous polychaetes of which *Onuphis eremita oculata* and *Diopatra cuprea cuprea* are the most abundant.

Species	Abundance
Bivalves	
Chione intapurpurea	frequent
Laevicardium pictum	frequent
Laevicardium laevigatum	rare
Macrocallista maculata	rare
Aequipecten gibbus	very rare
Chione grus	rare
Pandora trilineata	rare
Atrina serrata	rare
Tellina spp.	frequent
Eucrassitella speciosa	rare
Tellina alternata	frequent north of outcrop
Tellina lintea	frequent north of outcrop
Macoma tenta	frequent north of outcrop
Diplodonta punctatus	rare
Cooperella atlantica	rare
Gouldia cerina	rare

Varicorbula operculata	rare
Verticordia ornata	rare
Chione latilirata	rare
Plicatula gibbosa	rare
Corbula swiftiana	frequent near outcrop
Corbula barrattiana	frequent near outcrop
Corbula krebsiana	rare
Lucina nassula	rare north of outcrop
Venericardia perplana	rare near outcrop
Thyasira trisinuata	rare
Anatina plicatella	rare north of outcrop
Anatina lineata	rare north of outcrop
Gastropods	
Conus stearnsi	rare
Cerodrillia perryae	rare
Epitonium angulatum	rare
Pleuroploca gigantia	rare at outcrop
Fasiolaria tulipa	rare
Cassis tuberosa	rare
Murex pomum	rare at outcrop
Muricopsis ostrearum	rare
Terebra protexta	rare
Niso interrupta	rare
Nassarium albus	rare
Rubellatoma diomedia	rare
Lobiger pilsbryi	rare north of outcrop
Polinices lacteus	frequent near outcrop
Sinum perspectivum	rare
Busycon contrarium	rare
Crepidula	locally common
Scaphopoda	
Dentalium eboreum	frequent north of outcrop
Echinoderms	
Encope michelini and *E. aberrans*	locally abundant
Plagiobrissus grandis	locally abundant
Astropecten articulata	frequent
Luidia clathrata	locally common
Luidia alternata	rare
Echinaster modestus	locally common
Holothuria princeps	rare
Lytechinus variegatus	very rare
Bryozoa	
free-living	
Discoporella umbellata	common deeper than 60 feet
Cupularia doma	?
Cupularia biporosa	?
erect	
Bugula neritina	frequent
encrusting	
Stylopoma spongites	?
Exechonella antillea	?
(?)Trypostega venusta	?

Schizoporella floridana	?
Schizoporella cornuta	?
Parasmittina spathiolata	?
Hippoporina porosa	?
Microporella tractabilis	?
Cleidochasma contractum	?
Celleporaria brunnea	?
Hippoporella cf. *H. gorgonensis*	?
Floridina antigua	?
Parasmittina signata	?
Antrapora tincta	?
Scleractinia	
Astrangia astreiformis	rare
Enteropneusts	
Balanoglossus sp.	rare
Lancelets	
Branchiostoma caribbaeum	common
Polychaetes	
Nephtys picta	frequent
Lumbrineris inflata	abundant inner offshore sand plain
Arabella iricola	?
Ceratonereis irritabilis	abundant
Axiothella mucosa	?
Onuphis quadricuspis	?
Drilonereis sp.	?
Cistenides gouldii	frequent
Sthenelais articulata	?
Glycera americana	?
Glycera aff. *G. tenuis*	?
Onuphis magna	scattered small aggregations
Neanthes arenaceodonta	?
Notomastus hemipodus	?
Aricidea jeffreysi	?
Megalomma lobiferum	rare
Chloeia viridis	rare
Chaetopterus variopedatus	frequent north of outcrop
Glymenella torquata calida	rare north of outcrop
Diopatra cuprea cuprea	abundant north of outcrop rare elsewhere
Onuphis eremita oculata	very abundant north of outcrop, rare elsewhere
Loima medusa	rare north of outcrop
Lepidametria commensalis	rare north of outcrop
Polyodontes aff. *P. maxillosus*	rare north of outcrop
Corallinacaea	
Neogoniolithon sp.	common deeper than 60 feet

Molluscan species found on both the shoreface and the offshore sand plain were not included in the above list. For the complete assemblage see figures 39 and 40.

Limestone Bottom

Generally, the biota of the limestone substrate is uniformly distributed within the biotope. However, on a small scale, complex heterogeneities are found in the distribution patterns of most invertebrate groups. The larger epibenthic organisms or colonies are substrates for the development of associations of smaller invertebrates. For example, the alcyonarian *Lophogorgia hebes* often supports clusters of the byssally attached bivalve *Pteria colymbus* which in turn are substrates for associations of the erect bryozoans *Bugula neritina, Scrupocellaria regularis,* and *Gemellipora eburnea,* the encrusting form *Cleidochasma contractum,* encrusting coralline algae, barnacles, and encrusting sponges. *Arca umbonata,* a common rock-dwelling bivalve, is heavily encrusted by growths of the same species and groups but with the bryozoans *Crassimarginitella leucocypha* and *Microporella tractabilis* as well.

The need for stable substrate prevents most of the larger limestone-associated species from successfully colonizing the adjacent sand plain. Some of the smaller or more robust epibenthic species are able to utilize large shells and fragments as substrate in the sand. Those invertebrates restricted to the limestone are indicated with an asterisk below.

Species	Abundance
Bivalves	
Chama congregata	abundant
**Chama macerophylla*	frequent
**Arcopsis adamsi*	frequent
**Arca umbonata*	common
**Arca zebra*	rare
**Barbatia tenera*	frequent
**Barbatia domingensis*	abundant
**Pteria colymbus*	common
Anomia cimplex	common
Chione grus	common

Scapharaca transversa	frequent
Plicatula gibbosa	common
**Lithophaga bisulcata*	common
Gastropods	
**Calliostoma euglyptum*	rare
**Neosimnia uniplicata*	rare
**Cyphoma gibbosa*	rare
**Diadora cayenensis*	common
Crepidula fornicata	common
Crepidula aculeata	common
Crepidula plana	common
Fasiolaria tulipa	rare
Murex pomum	rare
Pleuroploca gigantia	rare
Echinoderms	
Lytechinus variegatus	frequent
**Arbacia punctulata*	frequent
**Echinaster braziliana*	frequent
Alcyonaria	
**Leptogorgia virgulata*	abundant
**Lophogorgia hebes*	abundant
Scleractinia	
**Solenastrea hyades*	frequent
**Siderastrea* sp.	frequent
**Cladocora arbuscula*	common
**Phyllangia americana*	abundant
Astrangia astreiformis	abundant
Bryozoa	
erect	
Bugula neritina	abundant
**Scrupocellaria regularis*	abundant
**Gemellipora eburnea*	common
encrusting	
Stylopoma spongites	?
Exechonella antillea	?
(?)Trypostega venusta	?
Schizoporella floridana	?
Schizoporella cornuta	?
Parasmittina spathiolata	?
Hippoporina porosa	?
Microporella tractabilis	?
Cleidochasma contractum	?
Crassimarginitella leucocypha	?
Celleporaria brunnea	?
Hippoporella cf. *H. gorgonensis*	?
Floridina antigua	?
Parasmittina signata	?
Antrapora tincta	?
Parasmittina nitida	?
Sponges	
**Placospongia carinata*	common
**Axinella* sp.	common

*(?)*Hemectyon* sp.	common
**Cliona celata*	common
**Cliona* cf. *C. euryphylla*	common
**Higginsia strigilata*	common
**Pleraplysilla* sp.	common
Algae	
**Codium isthmocladum*	frequent
**Caulerpa sertularioides*	common
**Cladophora* sp.	?

Communities

Although there is considerable theoretical disagreement as to the precise meaning or usage of the term "community" (see MacFadyen, 1963), in practice two distinct views of animal communities as organism associations can be distinguished. Johnson (1964) described benthic communities as "associations of largely independent species that occur together because of similar responses to the physical environment." At the other end of the spectrum is the concept of the biocoenosis, first proposed by Mobius (1877). The biocoenosis is characterized as an integrated ecologic unit composed of populations of species which co-act and interact with each other and the physical environment in an ordered dynamic system.

In reality, few animal associations have been studied in sufficient detail to permit unqualified recognition of interdependent behavior. Communities continue to be defined, as an extension of Peterson's (1914) pioneer work, on the basis of recurrent associations of species often with the implicit assumption that these associations do indeed reflect ecologic reality (Thorson, 1957). Others (Bretsky, 1973, and Valentine, 1973) regard the community as a useful descriptive unit with no special biologic significance. MacGinity's (1939) definition of a community as "an assemblage of animals or plants, living in a common locality, under

similar conditions of environment and with some apparent association of habitats" embodies both the physical and biologic attributes of an animal association and is the sense in which the term "community" will be used hereafter.

Thorson (1957) reviewed the distribution of level bottom benthic associations and concluded that communities which were ecologic parallels of those described by Petersen (1914) for the Danish Sea could be recognized worldwide. These parallel communities are characterized by the same generic dominants but differ at the specific level. The concept of parallel communities may be extended to level bottom associations in the present study area.

Thorson (1957) described a group of parallel *Tellina* communities which inhabit nearshore, shallow marine waters off exposed beaches characterized by species of *Tellina, Donax, Dosinia, Astropecten,* and *Terebra*. In the research area, the nearshore zone is dominated by species of some of those same genera, in particular *Donax variabilis* and *Terebra cinerea*. The distribution of the dominants is consistent with the concept of the community as a spatially distinct association of species which recur under similar environmental conditions. Thorson (1957) included a similar Texas coast assemblage in the Atlantic *Tellina tenera* community. We may therefore conclude that the Florida nearshore *Donax variabilis* community is a variant or parallel within the *Tellina* coastal community complex.

Communities of the open sea and sandy bottom are included by Thorson in the parallel *Venus* communities. Characterizing genera are *Venus, Spisula* (or *Mactra*), *Tellina, Natica* (or *Polinices*), *Astropecten,* and the irregular urchins *Echinocardium* or *Spatangus*. Where the sand

becomes fine with increasing amounts of silt the Tellinidae become dominant. Where the sand is coarse with much shell, *Branchiostoma* is abundant. The assemblage of the offshore sand plain is in many respects an ecologic parallel for the *Venus* community. Although the genus *Venus* does not occur there, the venerids *Chione intapurpurea* and *Macrocallista maculata* are its replacements. *Spisula* seems to be confined to shallower water but other characterizing genera are present including the irregular urchin *Plagiobrissus grandis* and *Branchiostoma*.

North of the limestone outcrop the presence of fine cohesive sand and silt creates favorable conditions for the development of a distinct assemblage dominated by tubiculous polychaetes and including an expanded population of deposit feeding tellinids. This community is in some respects similar to the *Tellina* facies of the *Venus* community but is sufficiently distinct and localized that no direct parallel can be recognized.

The shoreface faunal zone is an area of transition from the nearshore *Donax variabilis* community to the offshore *Venus* parallel community. The ranges of species overlap across the shoreface consistent with a trend of seaward increasing diversity. While the coastward boundary of this zone is somewhat distinct, due to the coherence of the *Donax* community, the lower boundary is probably entirely gradational with the offshore *Venus* parallel community. The only distinguishing faunal characteristics of the shoreface is the occurrence in abundance of *Balanoglossus* sp. and the bivalves *Strigilla mirabilis* and *Ervilia concentrica*. Until a more complete sampling of the living fauna is accomplished, the biota of the shoreface is not sufficiently distinct to warrant its recognition as a separate community. This assemblage will therefore be regarded as a

biofacies of the *Venus* parallel community representing a response to depth-related environmental factors.

The biota of the limestone substrate, in its density, diversity, and substrate inter-relationships represents most closely the concept of the biocoenosis. New niches are created and pre-existing ones modified by the crowded intergrowths of epibenthic species. Under such conditions biologic competition for available substrate and nutrients must exert the overriding control.

Thanatocoenosis

The thanatocoenosis or taphocoenosis of Schafer (1972) is the accumulated biogenic remains of the living community. The character of the thanatocoenosis, that is, its species composition, size distribution, and preservation, reflects not only the nature of the original community but also biological and physical processes which impose post-mortem changes on its constituent skeletal grains. When evaluated in the light of known community and population distributions, the thanatocoenosis may therefore yield considerable information concerning the mechanisms involved in its formation. The distribution and composition of the thanatocoenosis in the research area were studied through graphical and statistical analyses of frequency data obtained from semiquantitative samples.

Composition and Distribution

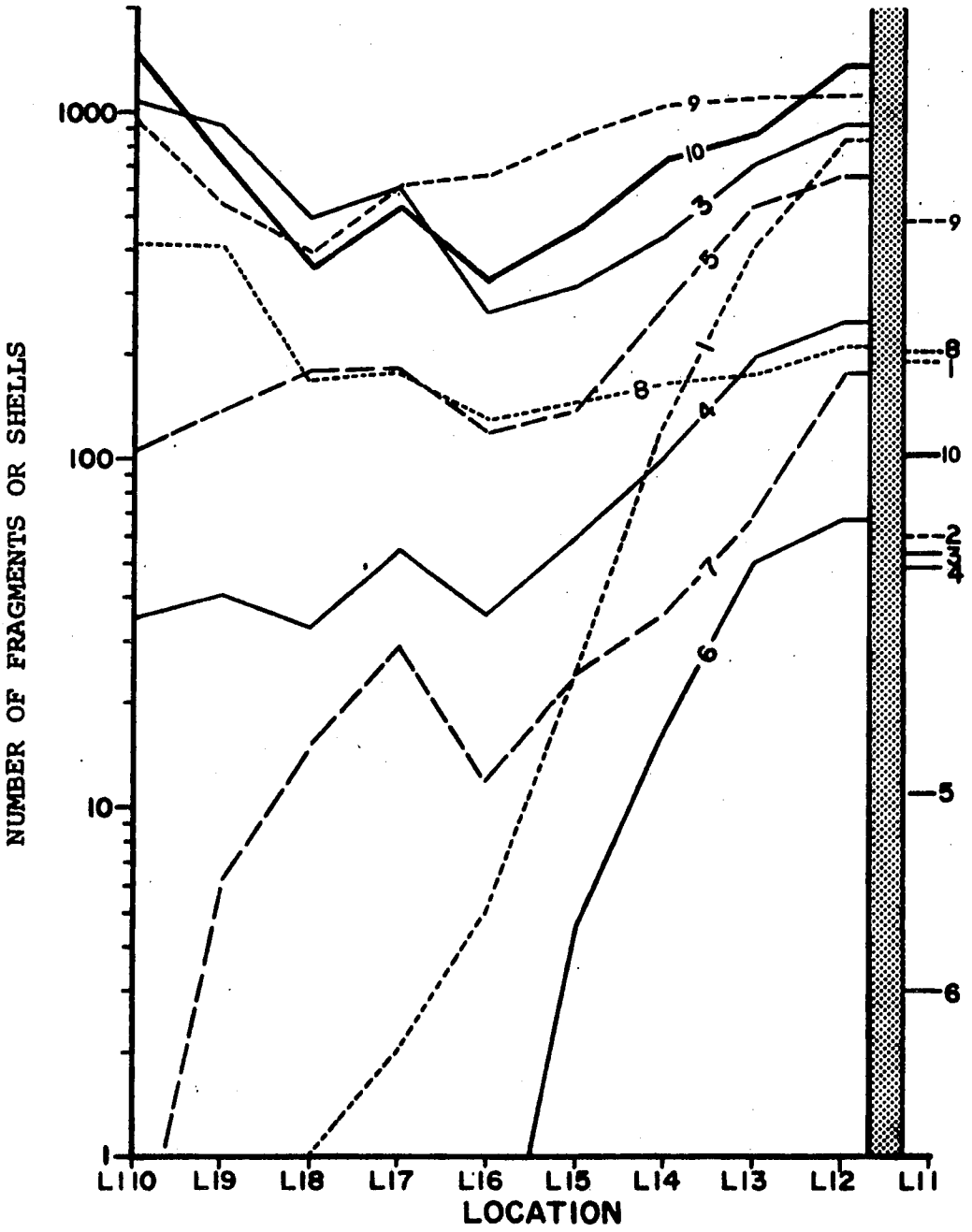
Four groups of macroinvertebrates contribute significant coarse (>2.38mm) biogenic material to the sediment: 1) mollusks, 2) echinoids,

3) coralline algae, 4) crustaceans. Minor constituents of the thanatocoenosis are cupularid bryozoan colonies and peneroplid Foraminifera. Mean frequency data for locations on lines L1, L2, and RL1 are summarized in Figures 41-43 and Figures 44-46 in terms of fragments and shells per 100 grams of biogenic material and relative frequency, respectively. Bivalve frequency was determined as the combined number of unbroken and broken valves. Each valve was regarded as a single specimen. Other groups, with the exception of coralline algae, are only rarely encountered as whole specimens in semiquantitative samples.

Of the major components, mollusks and echinoids together compose between 63 and 97 percent of biogenic grains larger than 2.38mm. Coralline algae (principally *Neogoniolithon* sp.) becomes of importance in deeper water constituting a maximum of 30 percent of biogenic material south of the limestone outcrop. Crustacean fragments, both barnacles and others, maintain a low but consistent frequency in the samples. Statistical analyses of the percent distribution on lines L1 and L2 indicate several trends in composition which warrant further discussion.

Analysis of variance of percent bivalve shells (unbroken and broken) on lines L1 and L2 indicates that no significant difference exists ($P>.05$) in mean percentage either among locations or between traverse lines. However, highly significant differences in mean percentage do occur among locations within traverse line and between corresponding locations of lines L1 and L2. These differences are related to opposed trends in bivalve distribution on the two traverse lines; bivalve percentages diminish with increasing distance from the coast on line L2 while they remain constant on line L1. The failure to find significant differences in main effects suggests that, although local variations may

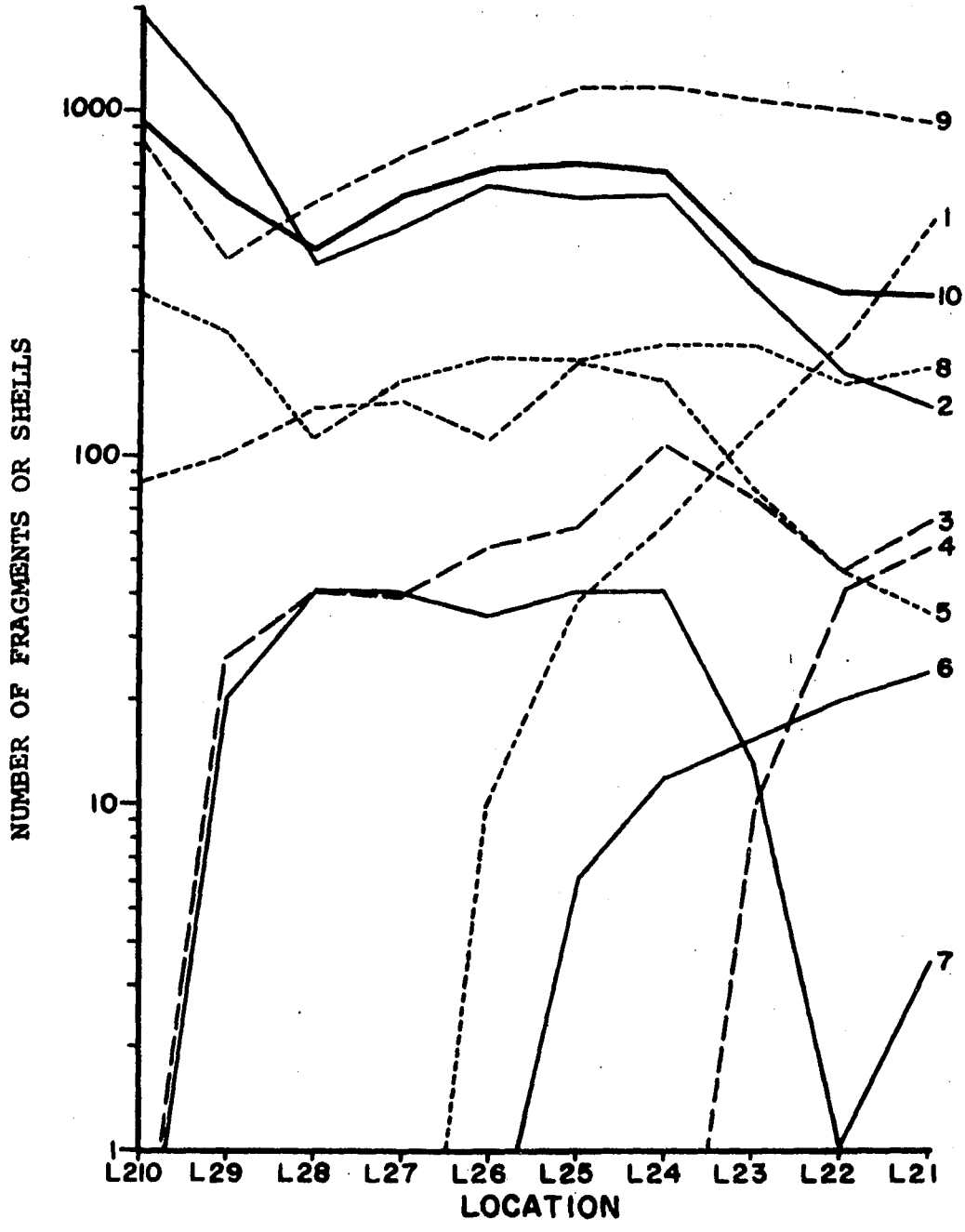
Figure 41



1-Coralline algae
2-Opercula
3-*Encope* spp. fragments
4-Barnacle fragments
5-*Plagiobrissus grandis* fragments
6-Bryozoan zoaria
7-Peneroplids
8-Gastropods and gastropod fragments
9-Bivalve fragments
10-Bivalves (unbroken + broken)

Average Number of Fragments or Shells of the Above Grain Types Found in 100 Grams of Biogenic Material at Locations on Line L1. Outcrop Area Stippled.

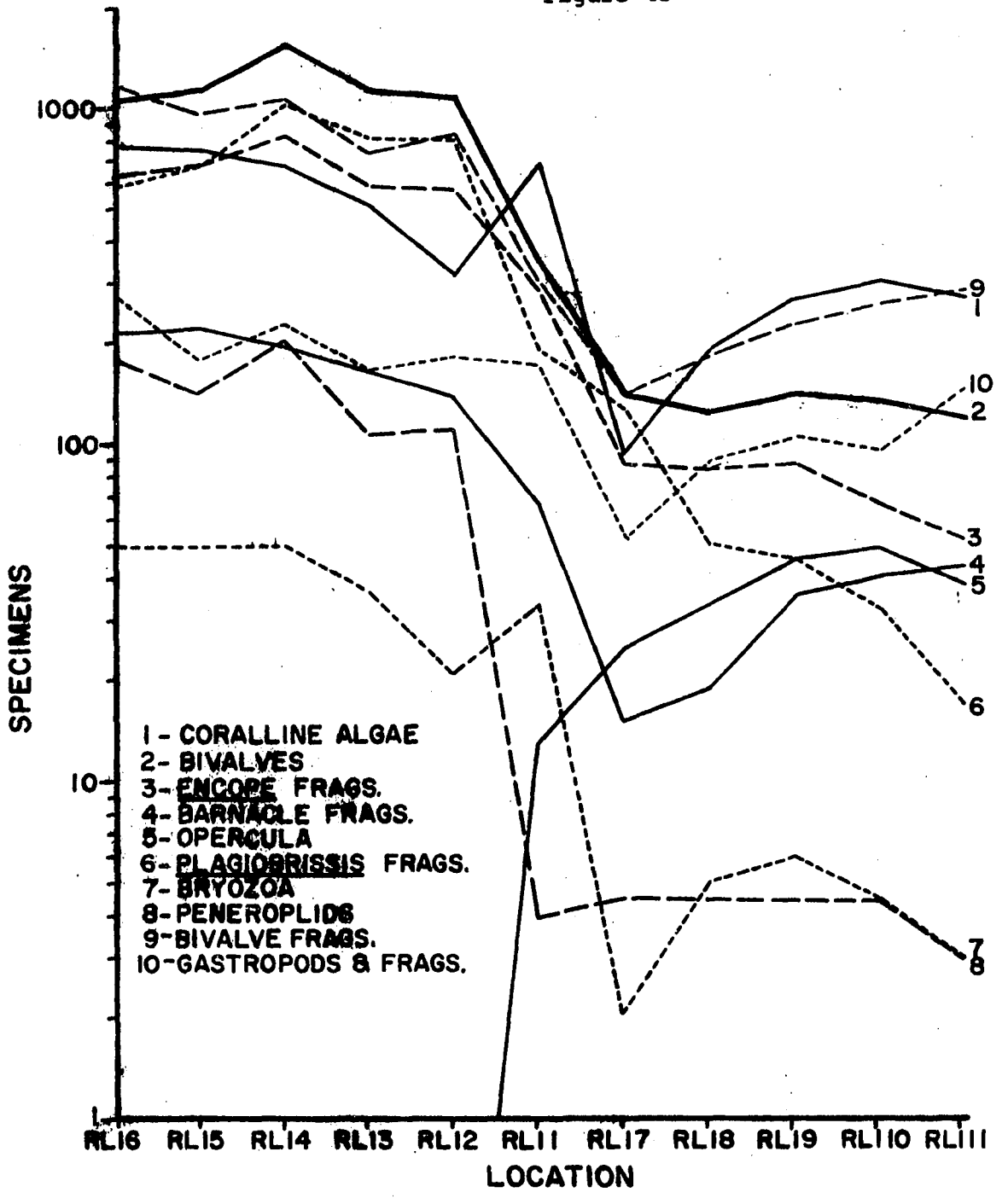
Figure 42



1-Coralline algae
2-Encope spp. fragments
3-Barnacle fragments
4-Opercula
5-Plagiobrissus grandis fragments
6-Bryozoan zoaria
7-Peneroplids
8-Gastropods and gastropod fragments
9-Bivalve fragments
10-Bivalves (unbroken + broken)

Average Number of Fragments or Shells of the Above Grain Types Found in 100 Grams of Biogenic Material at Locations on Line L2.

Figure 43



Average Number of Fragments or Shells of the Above Grain Types Found in 100 Grams of Biogenic Material at Locations on Line RL1.

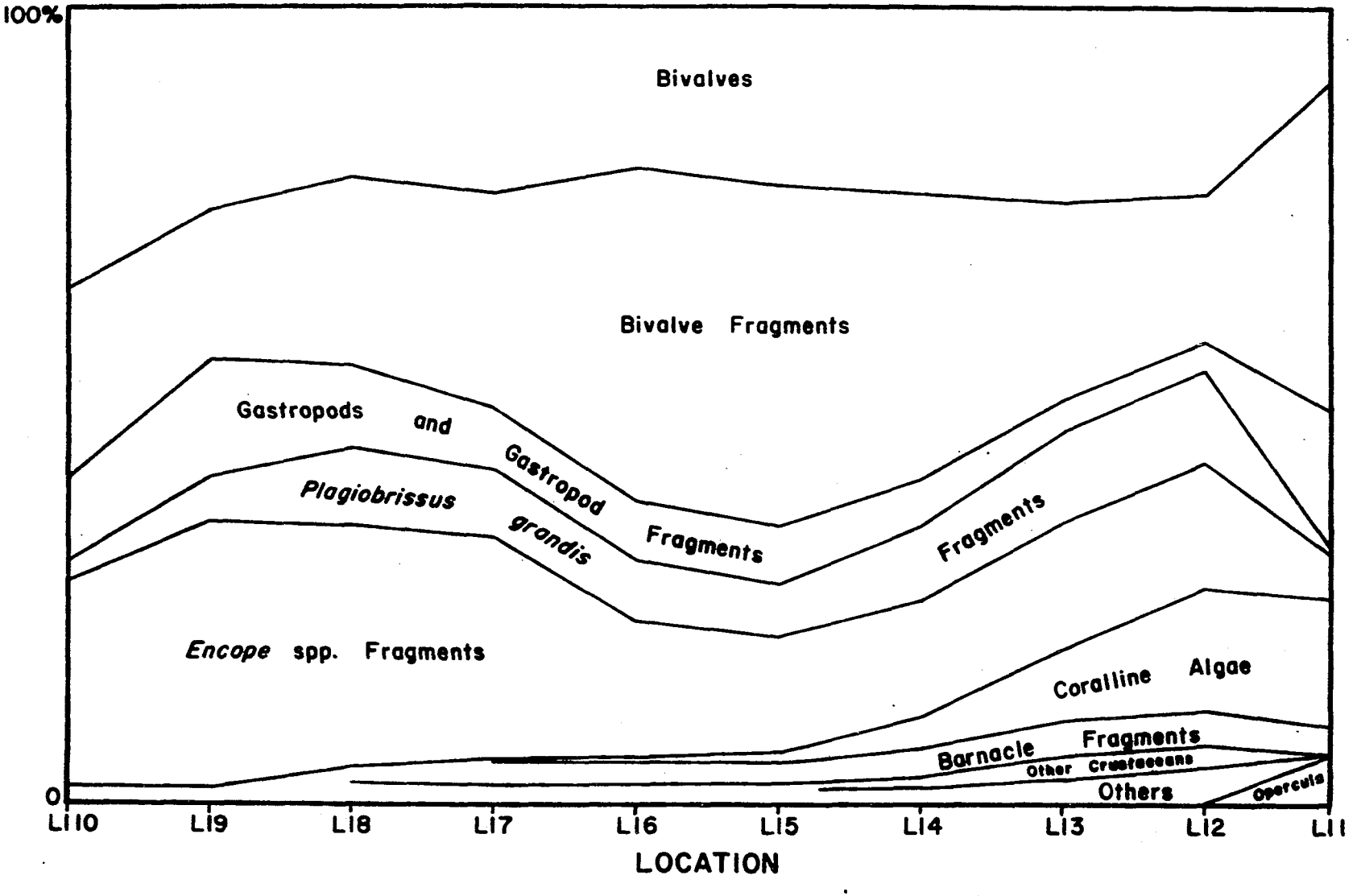


Figure 44. Mean Relative Frequency of Major Biogenic Grain Types - Line L1

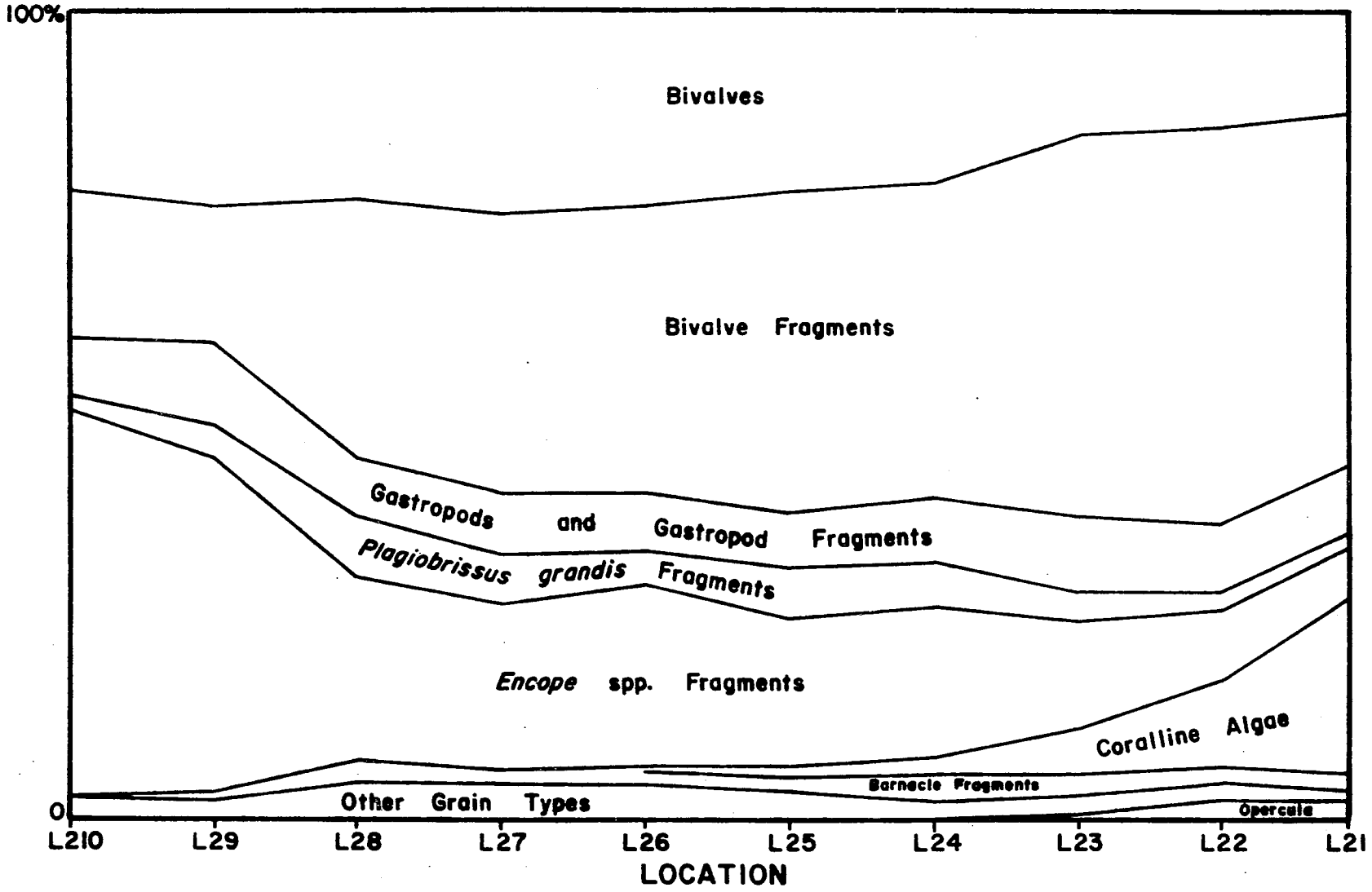


Figure 45. Mean Relative Frequency of Major Biogenic Grain Types - Line L2

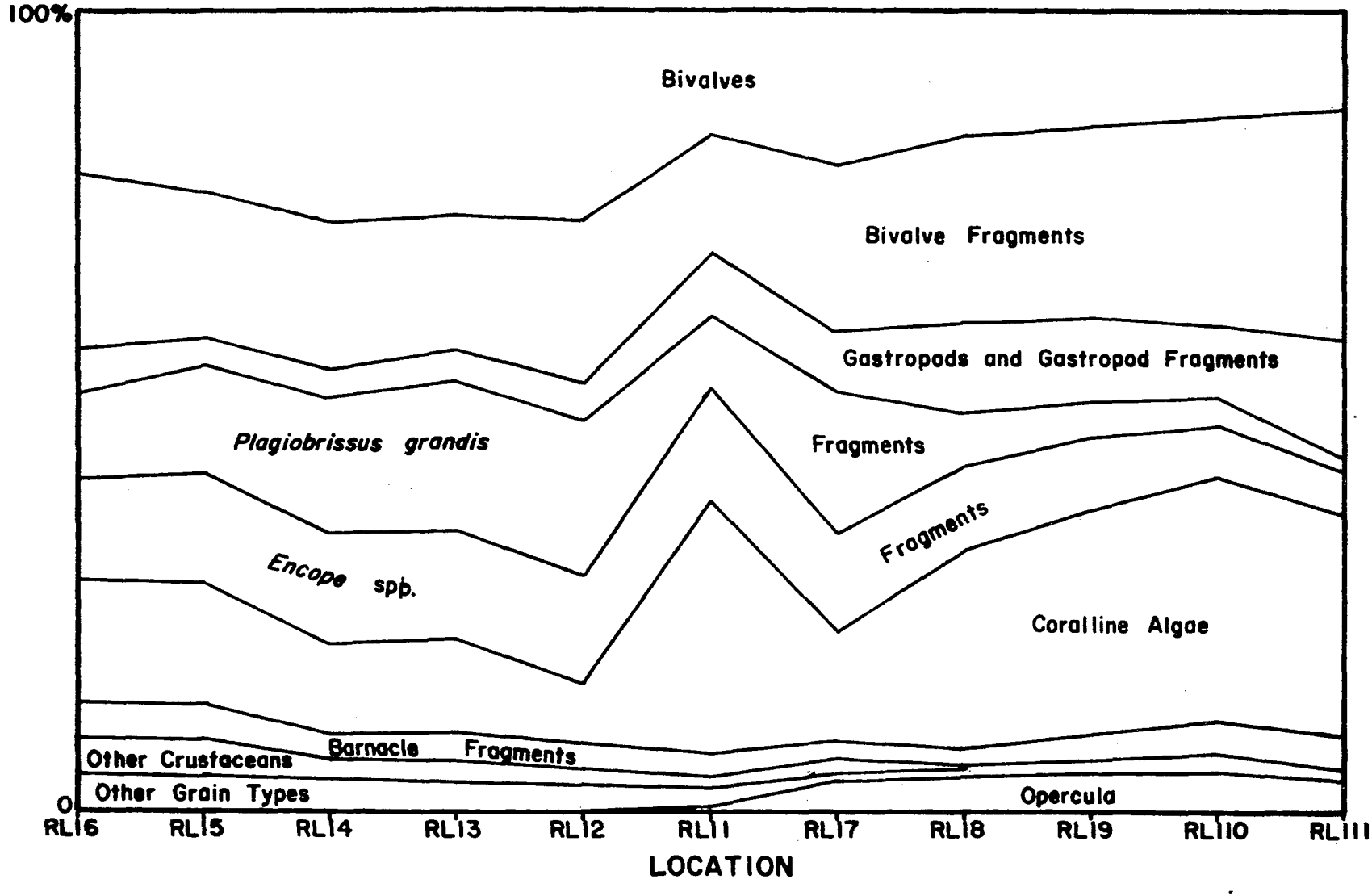


Figure 46. Mean Relative Frequency of Major Biogenic Grain Types - Line RL1

be found in the contribution of unbroken and broken bivalves to the thanatocoenosis, the bivalve shell percentage may be represented by an average of 21.8 percent for the level bottom.

The percentage of bivalve fragments undergoes highly significant variations both among locations and between traverse lines; the differences between traverse lines are also highly inconsistent among locations. These variations arise from pronounced and somewhat opposed trends in bivalve fragment percentage. On line L2 bivalve fragments increase in relative frequency regularly with distance from the coast or depth. However, on line L1 the percentage increases seaward to a maximum at location L15 then decreases to a minimum at location L12. Correlation analysis indicates that these trends can be explained as a highly significant negative linear relationship ($r=-.80^{**}$) of percent bivalve fragments with terrigenous sediment grain size (ϕ).

The combined mean percentage of gastropods and gastropod fragments shows no variation either among locations or between traverse lines L1 and L2. However, highly significant differences exist among locations within traverse lines and between locations at equal distance from the coast. These differences arise from the opposed trends of diminishing percentage with distance from the coast on line L1 and constant percentage along line L2. The gastropods and gastropod fragments combined contribute an average of 8.3 percent throughout the research area.

Relative frequency of *Plagiobrissus grandis* fragments is highly variable both among locations and between traverse lines. The difference between traverse lines in mean percentage is consistent over locations; line L1 samples contain a significantly higher proportion of *P. grandis* fragments than do line L2 samples.

Encope spp. fragments are those of *E. michelini* and *E. aberrans* combined. Highly significant differences in percent *Encope* spp. fragments occur among locations, but no difference in percent was detected between traverse lines L1 and L2. However, the difference among locations was inconsistent for the two traverse lines. Correlation analyses indicate that these differences are related to a highly significant negative correlation of percentage *Encope* spp. fragments with distance from shore (depth). The interaction between locations and traverse lines arises from the more pronounced seaward decline in percentage on line L2.

Coralline algae (*Neogoniolithon* sp.) increases in contribution steadily from a frequency near 0 at locations L17 and L27 to a maximum of 21 percent of the biogenic grains at location L11. No statistical analysis was performed, but the distribution of *Neogoniolithon* sp. in the sediment appears to be consistent between traverse lines and well correlated with distance from the coast or depth.

Cupularid bryozoan colonies, primarily *Discoporella umbellata*, are distributed in low relative frequency in the sediment. Figures 41 and 42 indicate that their distribution is quite similar to that of *Neogoniolithon* sp. in being confined to deeper water at the seaward ends of lines L1 and L2.

Calcareous opercula, probably of the gastropod *Turbo castaneus*, are a minor but consistent component of the thanatocoenosis associated with the coarse-grained sands at the seaward ends of lines L1 and L2.

Percentage distribution of biogenic components found in samples taken on line RL1 is illustrated in Figure 46. Significant differences occur between samples from the north side and south side of the outcrop

as regards the percentage distribution of all grain types. Bivalves (unbroken and broken), *Plagiobrissus grandis* fragments, and *Encore* spp. fragments decrease in frequency of occurrence relative to increased percentages of bivalve fragments, gastropods and gastropod fragments, coralline algae, and opercula to the south. In addition, a pronounced increase in percentage of coralline algae occurs at location RL11, within the outcrop area.

Mollusks

Mollusks were selected for detailed quantitative analysis of species composition and distribution in the thanatocoenosis because of their high diversity and abundance. It was anticipated that variations in the distribution of mollusk shells, when compared with the living community, would provide a means of evaluating the degree of transportation and dispersal of biogenic material.

The mollusks of the thanatocoenosis are represented by 114 bivalve species, 95 gastropod species, and 3 scaphopod species. Several sources of molluscan shells can be recognized in the research area: 1) Late Pleistocene fossils derived from erosion of the limestone, 2) Early Holocene bay-inlet assemblages found on the offshore sand plain, 3) Late Holocene and modern assemblages.

1) Late Pleistocene fossils are rare in the sediments adjacent to the limestone outcrop. They are easily identified by preservation and do not constitute a source of confusion in the interpretation of the thanatocoenosis. Species identified as fossils are listed on page 51 of this report. They are, for the most part, species that are found living today on the offshore sand plain. The abundance of *Neogoniolithon*

sp. fragments in the limestone and the presence of *Discoporella umbellata* suggest a water depth of at least 65 to 70 feet when these fossils accumulated in Late Pleistocene time. The geologic history of the limestone body is developed on page 58.

2) Anomalous assemblages of gastropods and bivalves interpreted to be relict Early Holocene bay-inlet or very shallow marine species are found at locations on the offshore sand plain indicated on Figure 47. At some locations the shells of these species are found in distinct layers beneath the sand surface. At others, they are scattered over the sea floor as the most conspicuous component of the thanatocoenosis. Members of this relict assemblage were identified by 1) ecologic requirements inconsistent with the present environment, 2) poor preservation, 3) recurrent association in localized distributions, and 4) lack of associated living representatives.

Species

Bivalves

Mercenaria campechiensis
Chione cancellata
Noetia ponderosa
Anadara ovalis
Mulinia lateralis
Spisula solidissima
Mactra fragilis
Cumingia tellinoides
Cardita floridana
Glycymeris pectinata
Brachidontes exustus
Donax variabilis
Laevicardium mortoni
Trachycardium egmontianum

Gastropods

Modulus modulus
Turbo castaneus
Prunum apicinum
Pyramidella crenulata
Anachis avera semiplicata

Mercenaria campechiensis is frequently found alive around the margin of Choctawhatchee Bay. Occurrences of this species have been reported by McNulty et al. (1962) in Biscayne Bay, Ladd et al. (1957), Parker (1959, 1960), and Pulley (1952) in the polyhaline bays and passes of Texas, Parker (1956) in the upper sounds and inlets of the east

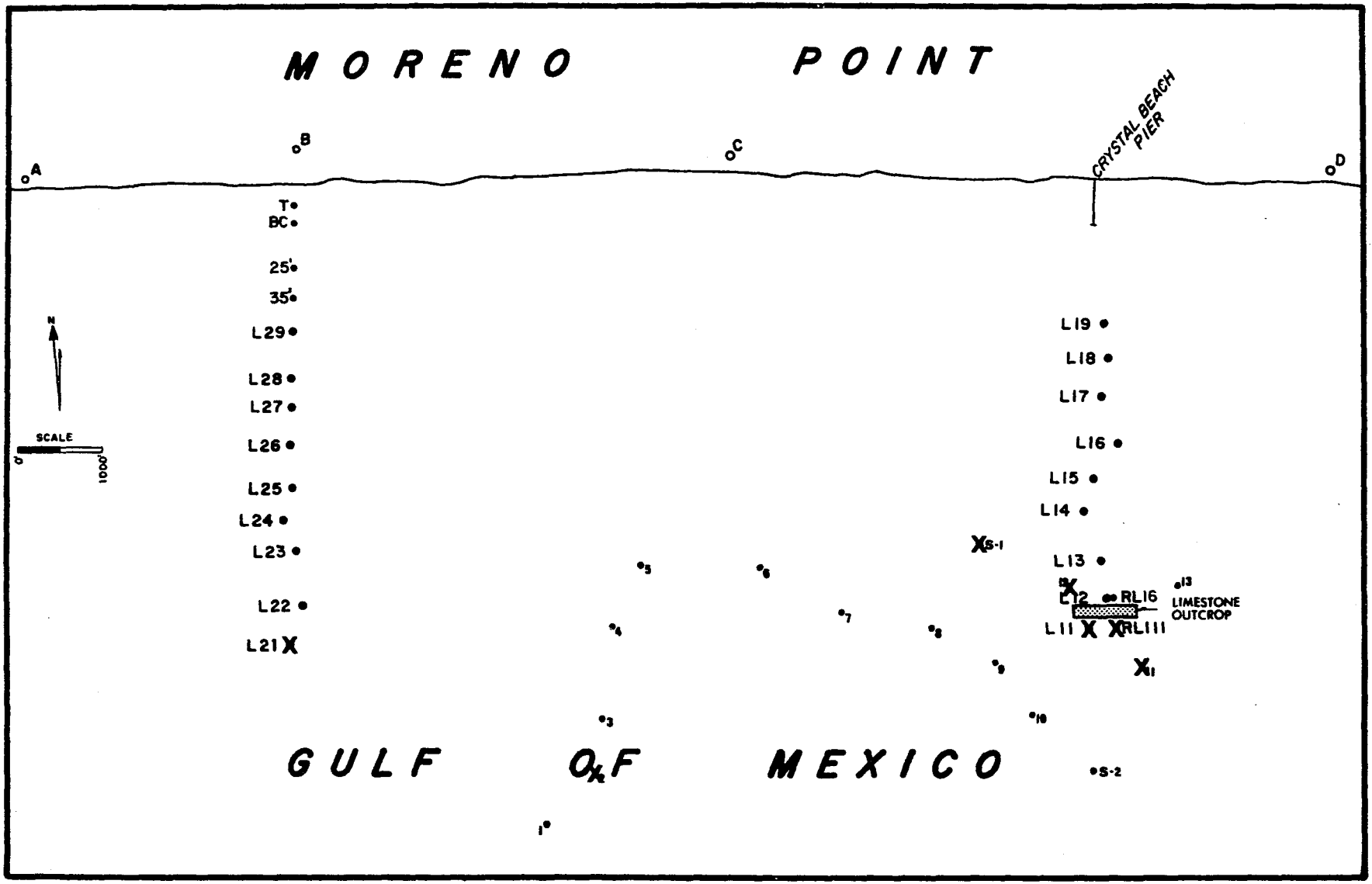


Figure 47. Location (X) of Relict Molluscan Assemblages.

Mississippi Delta, and Bloom (1972) in Tampa Bay.

Chione cancellata is the most abundant species of this group. Living populations of this species are known from open high salinity bays and inlets of Texas (Pulley, 1952; Parker, 1959, 1960; and Ladd, 1951), inlets of the east Mississippi Delta (Parker, 1956), enclosed bays, polyhaline bays and passes, and the shallow (-40 feet) Gulf of Mexico (Ladd et al., 1957 and Parker, 1960), Boca Ciega Bay (Dragovich and Kelly, 1964) and shallow Gulf waters in areas of reduced salinity near the mouth of Crystal River on the West Florida coast (Lyons et al., 1971). Well preserved shells of *C. cancellata* collected south of the limestone outcrop were radiocarbon age dated at 9070 ±370 years BP.

Noetia ponderosa inhabits shallow low energy open Gulf waters off the west coast of Florida (Lyons et al., 1971). However, Parker (1959, 1960) and Ladd et al. (1957) list this species as characteristic also of inlets and open sounds of Texas. Kritzler (personal communication) has found associations of *Noetia ponderosa* and *Scapharca transversa* near the shallow inlet of St. Josephs Bay, Florida.

Occurrences of living *Anadara ovalis (Arca campechiensis)* are described by Ladd et al. (1957) and Ladd (1951) as rare to frequent in polyhaline bays of Texas but rare in inlets and open nearshore Gulf waters. Parker (1956) found this species rarely in upper sound and inlet assemblages but frequently on the shallow shelf off the east Mississippi Delta. However, Parker (1959, 1960) described *A. ovalis* as characteristic of open high salinity bays and sounds of the Texas coast.

Mulinia lateralis is a common living species in open shallow coastal waters (Keith and Hulings, 1965, and Ladd et al., 1957). However, it is found most abundantly in hypersaline or polyhaline bays and sounds

where this euryhaline species thrives (Parker, 1959, 1960, 1956; Ladd, 1951; Ladd et al., 1957; and Dragovich and Kelly, 1964).

Spisula solidissima is frequently found alive in the nearshore zone but never deeper than 30 feet. It is characteristic of exposed coasts of the Atlantic and northern Gulf of Mexico (Abbott, 1954). *Donax variabilis,* a rare member of the relict thanatocoenosis, is abundant in the surf zone of Gulf beaches (Hedgpeth, 1953; Ladd, 1951) but does not inhabit bays or other bodies of quiet water.

Mactra fragilis inhabits open high salinity bay margins (Parker, 1959, 1960; Ladd et al., 1957; and Pulley, 1952), and possibly low energy shallow open Gulf waters (Lyons et al., 1971). Occurrences of living *Cumingia tellinoides* have been reported by Bird (1970) in the estuary of the Newport River, North Carolina, and by Ladd et al. (1957) in polyhaline bays and passes of the Texas coast.

Cardita floridana and *Glycymeris pectinata,* two common relict species, are found living in abundance in low energy Gulf coastal waters of western Florida at depths shallower than 30 feet (Lyons et al., 1971). *Cardita floridana* is also reported by Parker (1959, 1960) from shallow, grassy hypersaline lagoons and bays and by Ladd et al. (1957) from closed bays and polyhaline bays but rarely from passes and the nearshore Gulf.

Brachidontes exustus inhabits mangrove roots in areas of low salinity in Tampa Bay (Dragovich and Kelly, 1964) and high salinity shell reefs in enclosed Texas coastal bays (Parker, 1959, 1960).

Laevicardium mortoni is found alive in Choctawhatchee Bay. Living specimens have also been recovered from Tampa Bay (Bloom et al., 1972), Biscayne Bay (McNulty et al., 1962), the bays of Texas (Pulley, 1952; Parker, 1959, 1960; Ladd et al., 1957) but rarely in the shallow low

energy Gulf of Mexico of the West Florida shelf (Lyons et al., 1971).

The depth distribution of living *Trachycardium egmontianum* is problematic. Lyons et al. (1971) record several fresh empty shells at a depth of less than 30 feet at the mouth of Crystal River on the West Florida coast but claim that this species ranges from the intertidal zone to 60m. Abbott (1954) describes *T. egmontianum* as a common shallow water species. Its occurrence at least appears indicative of open Gulf conditions.

The gastropods *Modulus modulus, Turbo castaneus,* and *Prunum apicinum* are characteristic of shallow, grassy bottoms of hypersaline lagoons and bays in depths of 1 to 2 feet (Parker, 1959, 1960; Ladd et al., 1957; Dragovich and Kelly, 1964; and Smith, 1951). *Pyramidella crenulata* is reported by Parker (1959, 1960) from inlets, open sounds, and nearshore Gulf waters. Parker (1959, 1960) found *Anachis avera semiplicata* associated with *Brachidontes exustus* in high salinity shell reefs of Texas bays.

The relict assemblage described above probably represents the successive contribution of several different communities whose species composition changed as the area was progressively submerged by the Holocene sea level rise. Evidence for the presence of an Early Holocene bay, based on topography and sediments, was presented earlier. Relict species may be grouped into 1) enclosed bay species - *Brachidontes exustus, Mulinia lateralis, Anachis avera semiplicata,* 2) open polyhaline bay and sound species - *Laevicardium mortoni, Mercenaria campechiensis, Mactra fragilis, Cardita floridana, Cumingia tellinoides, Glycymeris pectinata, Mulinia lateralis, Anadara ovalis, Noetia ponderosa, Chione cancellata, Turbo castaneus, Modulus modulus, Prunum apicinum, Pyramidella crenulata,*

3) exposed coast species - *Donax variabilis, Spisula solidissima*. We may therefore conclude that the research area was at first occupied by an enclosed bay in Early Holocene time which gradually became an open sound and finally an exposed coast as sea level rose.

Other species of the thanatocoenosis may be unrecognized members of the relict assemblage even though they are found living in the study area. One such species is *Scapharca transversa* which frequently occurs as severely corraded adult shells on the offshore sand plain. This species is commonly associated in life in other areas with many of the species interpreted to be relict. *Scapharca transversa* is reported by Bloom et al. (1972) from Tampa Bay, Parker (1959, 1960) from open high salinity bays and sounds of Texas, Ladd et al. (1957) abundantly from polyhaline bays, passes, and the nearshore Gulf, and by Dragovich and Kelly (1964) from the low salinity muddy bottom of Hillsborough Bay, Florida.

3) Late Holocene and modern assemblages include species which are represented by living populations or, from published accounts, are compatible in distribution with the present environment.

Bivalves

In contribution of biogenic material bivalves constitute by far the most important molluscan group. The distribution and preservation of bivalve shells has accordingly received the most attention.

Diversity

The shells of ninety-four bivalve species are found in semiquantitative samples. Their distribution on a presence-or-absence basis at

locations on lines L1, L2, and RL1 is presented in Figures 48-50. Many bivalves are variable or inconsistent in their occurrence both within locations and among locations. In most cases inconsistency characterizes the rarer species; in others, it is a result of small average size which causes the species to be poorly represented in the samples. Species which occur consistently among samples within location also tend to occur consistently among locations indicating, at least qualitatively, a dispersed bivalve shell assemblage rather than one of a strongly clumped nature. Non-occurrence within or among locations often represents a random sampling error.

The number of bivalve species in the thanatocoenosis shows a strong positive correlation with depth (Figure 51). Species diversity increases seaward from an average low of 18 species per sample at 30 feet (locations L110 and L210) to an average high of 60 species at 70 feet for samples collected south of the limestone outcrop. The distribution is not without irregularity, however. The increase in diversity is most rapid to a depth of about 57 feet. In deeper water the number of species remains constant on line L2 or decreases on line L1 except at 70 feet where limestone substrate species and the relict assemblage contribute additional shells to the thanatocoenosis.

Relative Frequency - Of the 94 species found in semiquantitative samples, 23 species constitute between 65 and 90 percent of the bivalve shells, by number of single valves. They are as follows:

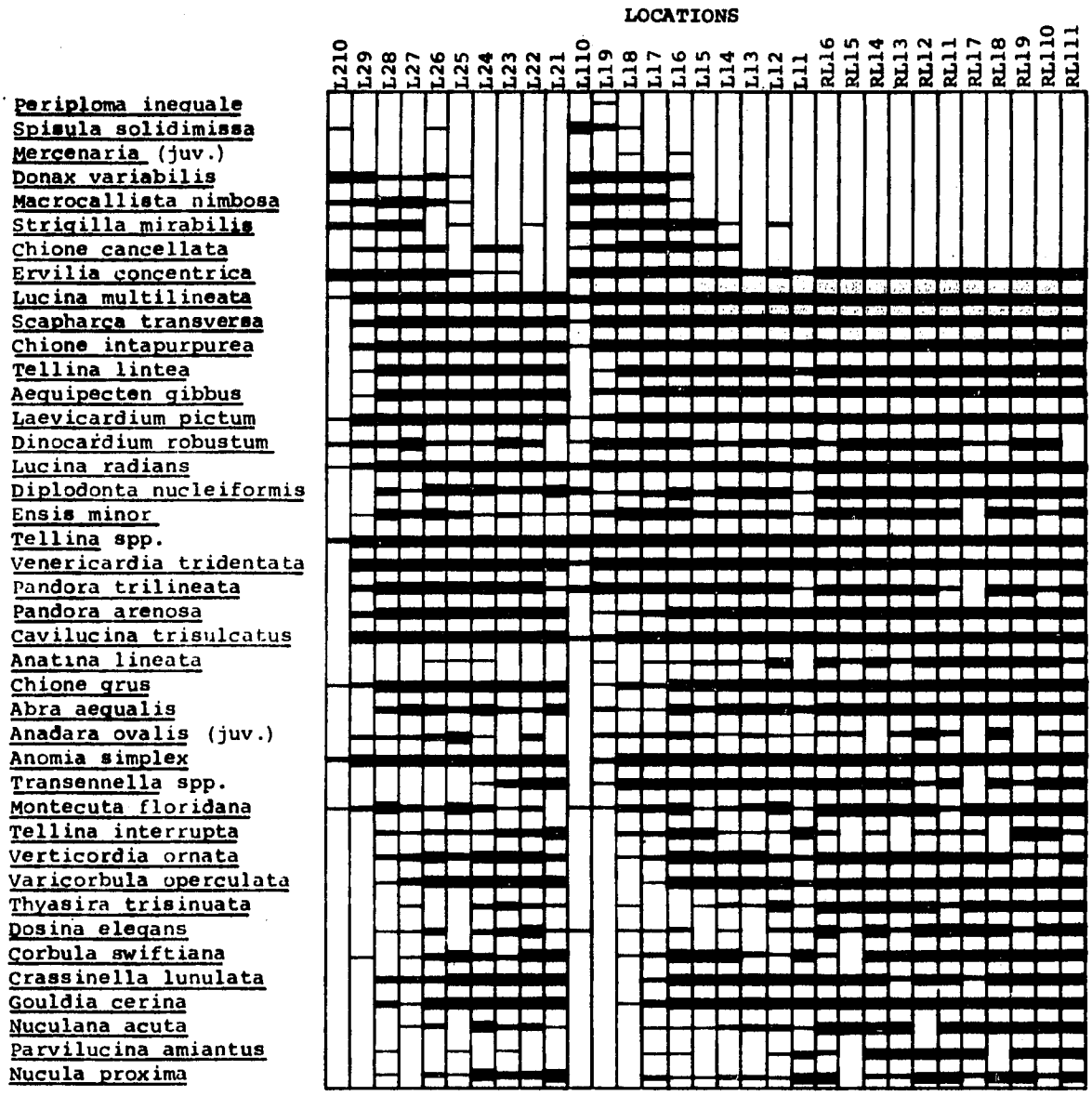


Figure 48. Occurrence of Bivalve Species (>2.38mm.) in Semiquantitative Samples at Locations on Lines L1, L2, and RL1

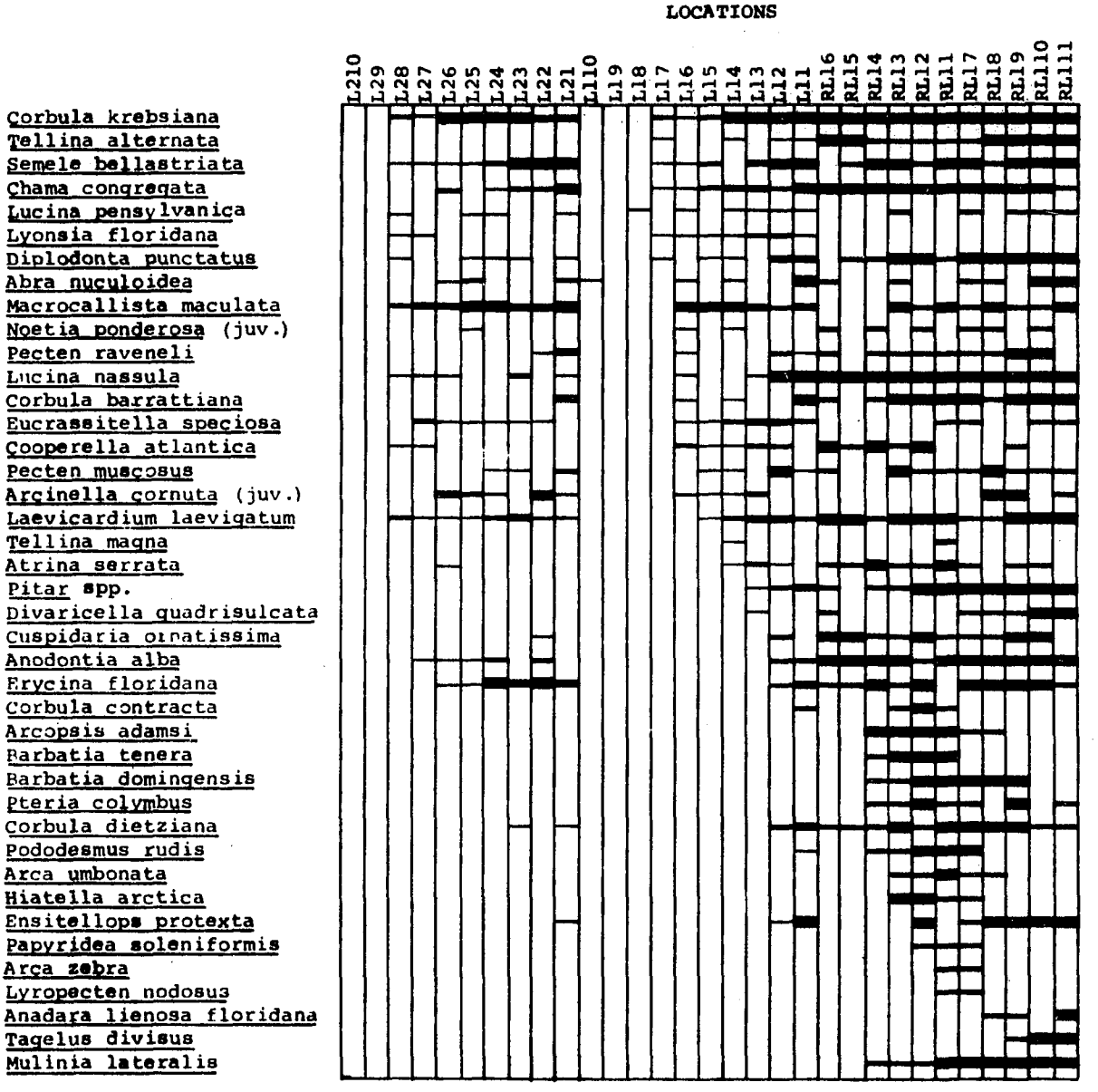


Figure 49. Occurrence of Bivalve Species (> 2.38mm.) in Semiquantitative Samples at Locations on Lines L1, L2, and RL1

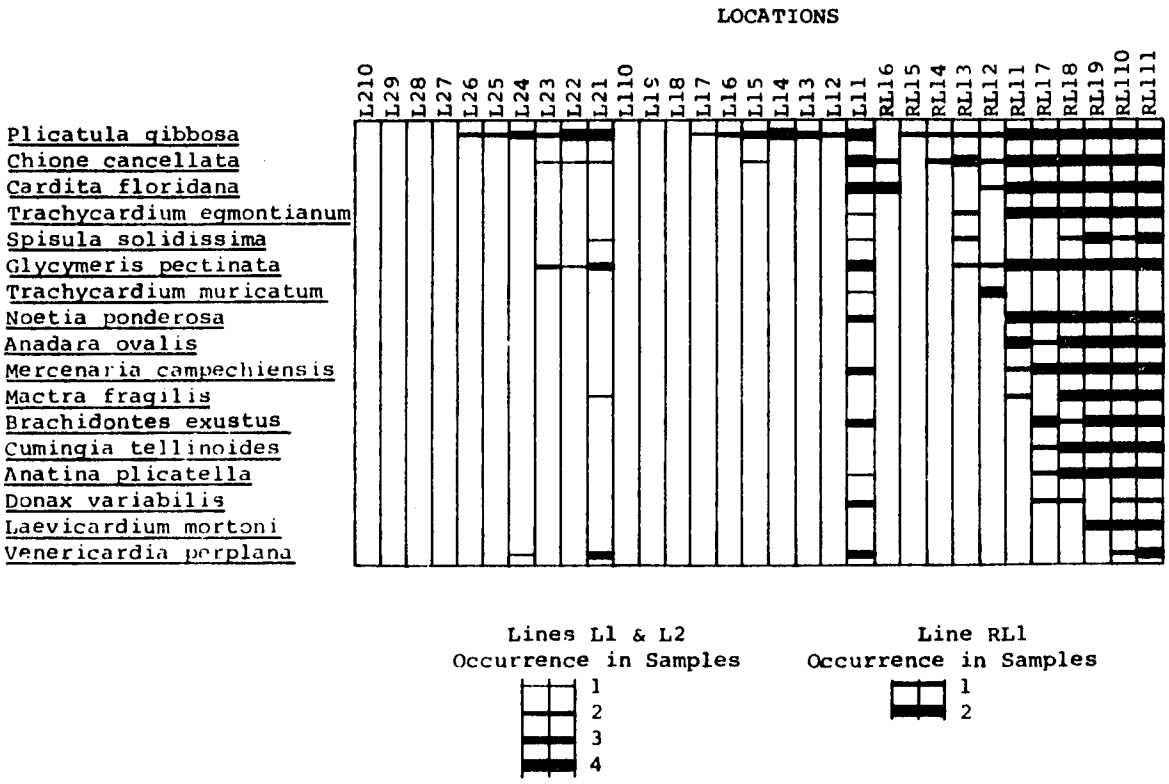
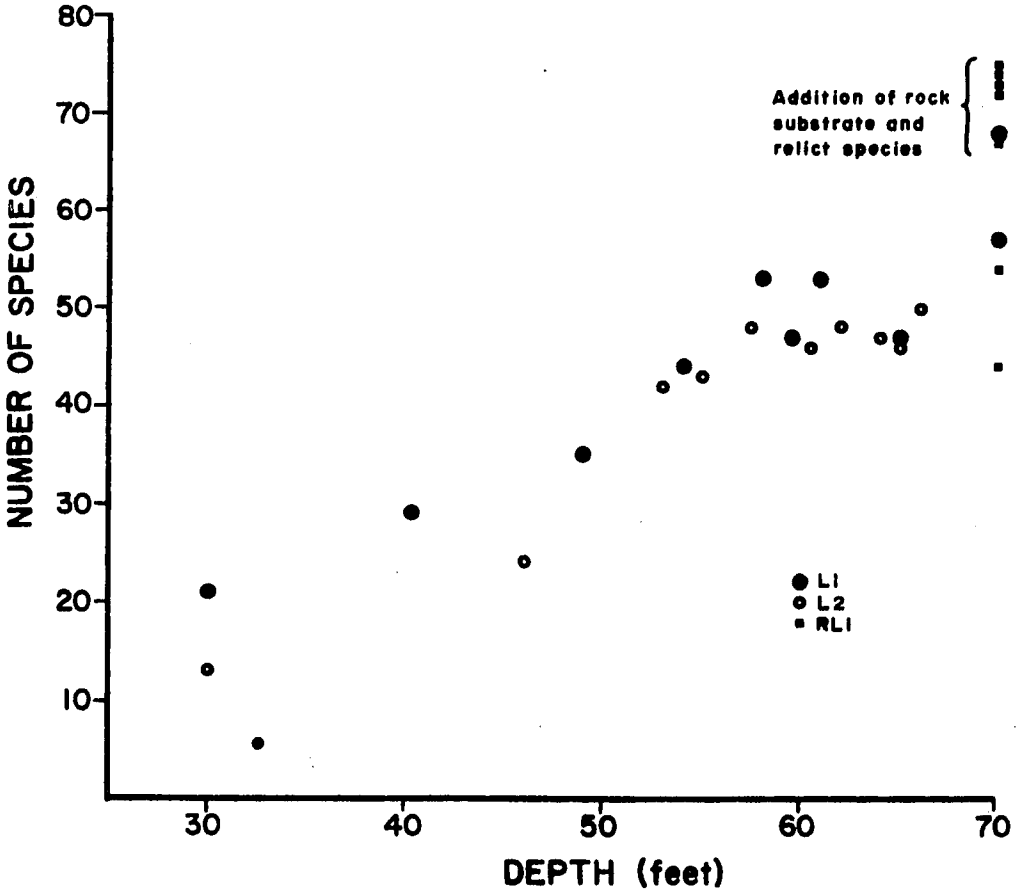


Figure 50. Occurrence of Bivalve Species (> 2.38mm.) in Semiquantitative Samples at Locations on Lines L1, L2, and RL1

Figure 51



Water Depth and Bivalve Species Diversity in the Thanatocoenosis. Number of species is the total within location.

Macrocallista nimbosa
Donax variabilis
Pandora trilineata
Cavilucina trisulcatus
Lucina multilineata
Venericardia tridentata
Varicorbula operculata
Laevicardium pictum
Anomia simplex
Plicatula gibbosa
Aequipecten gibbus
Chione cancellata (relict)
Stigilla mirabilis
Ervilia concentrica
Pandora arenosa
Lucina radians
Tellina spp.
Chione intapurpurea
Corbula krebsiana
Scapharca transversa
Chione grus
Gouldia cerina
Chama congregata

The relative frequency of occurrence of these species and others has been summarized in Figures 52-54 for locations on lines L1, L2, and RL1. These percentages are based on the sum of unbroken and broken valves of each species without regard to preservation. It is apparent that the frequency distribution exhibits patterns along lines L1 and L2 which are quite similar. Assemblages on the shoreface at locations L110, L19, L210, and L29 are dominated by the shells of *Macrocallista nimbosa, Strigilla mirabilis, Donax variabilis,* and *Ervilia concentrica.* On the lower shoreface at locations L18, L17, L28, and L27 *Cavilucina trisulcatus, Lucina radians,* and *Pandora trilineata* reach their relative maximums. *Chione intapurpurea, Venericardia tridentata, Laevicardium pictum,* and *Scapharca transversa* also increase in percentage at those locations and with *Varicorbula operculata, Corbula krebsiana,* and *Anomia simplex* compose 60 percent of the bivalves of the offshore sand plain. *Lucina multilineata* and *Tellina* spp. are distributed over all locations.

On both lines L1 and L2 the shoreface is a zone of rapidly changing relative frequencies with domination by few species being replaced seaward by a more diverse and uniform assemblage. At the seaward end of line L1 the presence of the limestone outcrop and the associated fine sand body and the relict fauna found at location L11 cause systematic

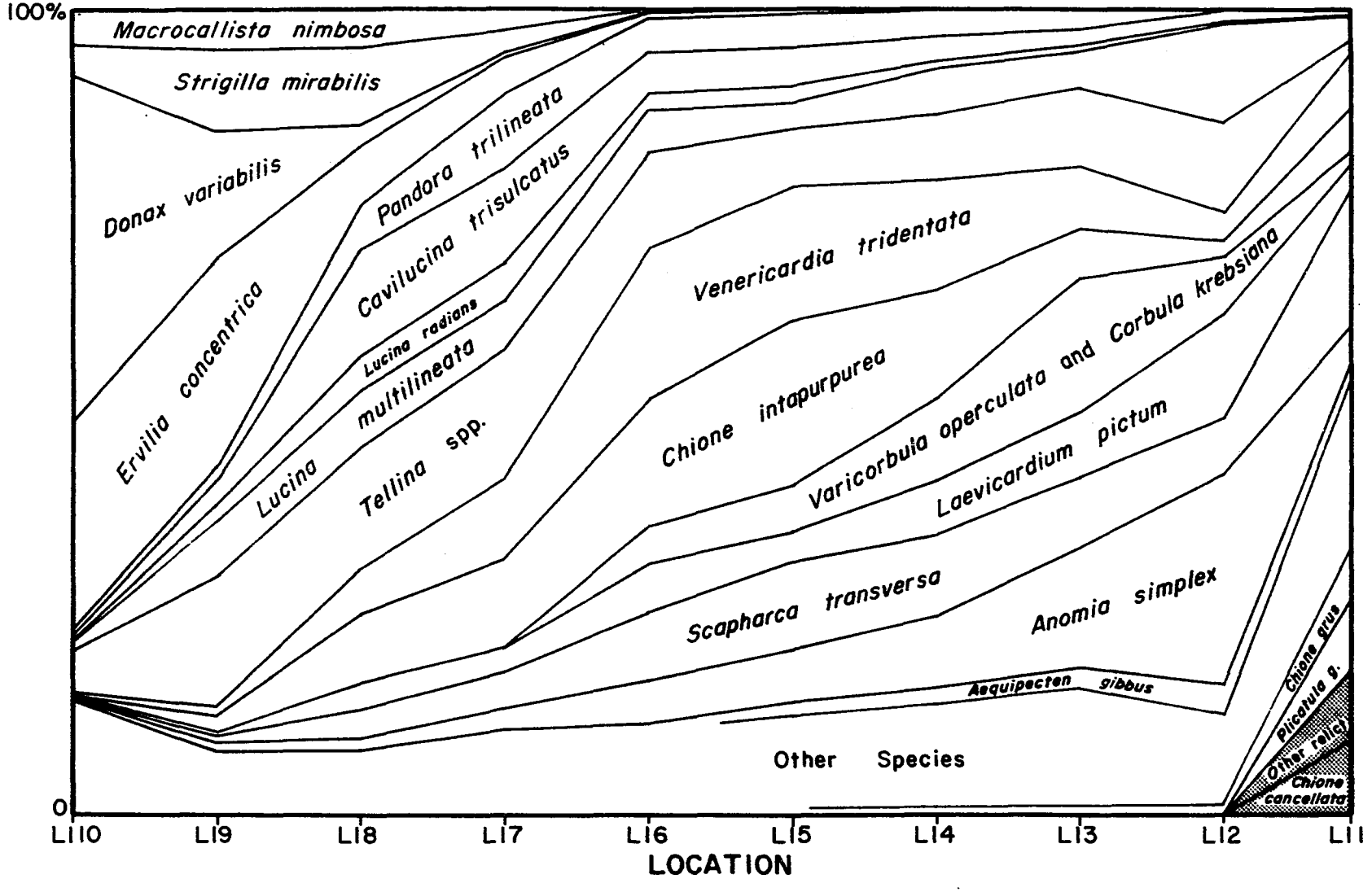


Figure 52. Mean Relative Frequency of Bivalve Species (>2.38mm.) at Locations on Line L1

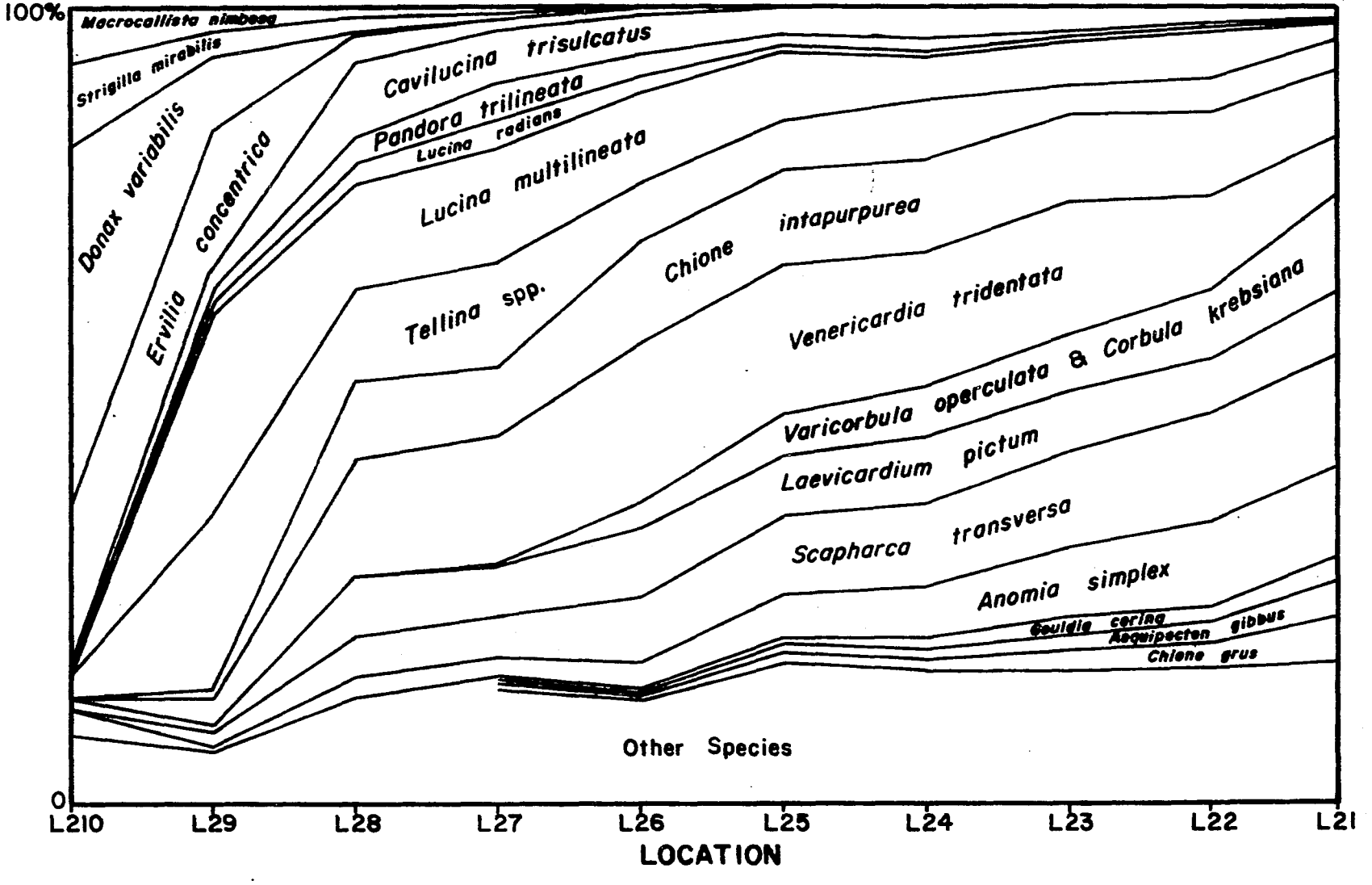


Figure 53. Mean Relative Frequency of Bivalve Species (>2.38mm.) at Locations on Line L2

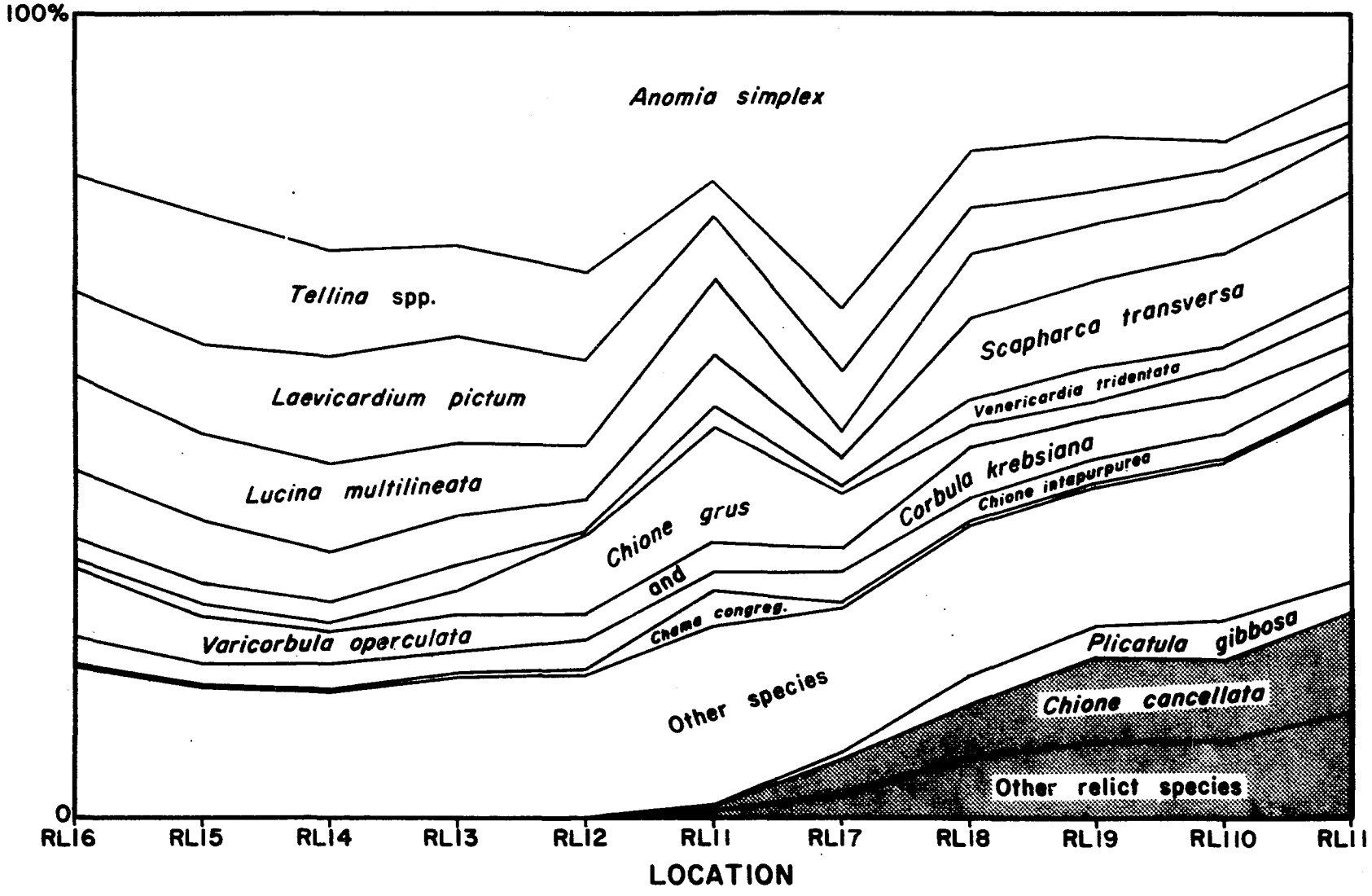


Figure 54. Mean Relative Frequency of Bivalve Species (>2.38mm.) at Locations on Line RL1

changes in the relative frequencies of most offshore sand plain species. North of the outcrop, in the fine sands, *Anomia simplex, Laevicardium pictum, Lucina multilineata,* and *Tellina* spp. increase in abundance relative to other components while south of the outcrop these species are reduced in percentage as the relative frequencies of relict species and *Scapharca transversa* increase.

Analyses of variance using a completely randomized design with a factorial arrangement of treatments were performed on the relative frequencies of the more common species in the thanatocoenosis to test for differences in mean percentage among locations and between traverse lines. The analyses were performed on locations 10 through 3 for lines L1 and L2; locations 1 and 2 were eliminated from the analyses because of between-traverse line depth and substrate differences at those locations whose effect could not be controlled. All species tested showed highly significant differences in mean percentage among locations as was expected from the pronounced seaward trends in distribution described above. *Anomia simplex, Donax variabilis, Cavilucina trisulcatus, Chione intapurpurea,* and *Scapharca transversa* percentages were not significantly different between lines L1 and L2; significant differences in mean percentage between traverse lines were found for *Ervilia concentrica, Venericardia tridentata,* and *Laevicardium pictum.* Significant interaction of main effects was found for these species, with the exception of *Donax variabilis, Ervilia concentrica,* and *Laevicardium pictum,* indicating inconsistency for the two lines in the effect of distance from shore (depth) on relative frequency. Only *Donax variabilis* is completely uniform in percent distribution between traverse lines. Significantly higher percentages of *Ervilia concentrica* occur on lines L1 while higher percent-

ages of *Laevicardium pictum* and *Venericardia tridentata* are found on line L2.

These findings suggest that, although the relative frequency distribution of bivalve species is qualitatively similar between lines L1 and L2, significant variations parallel to the coast are found in the relative frequency of some members of the thanatocoenosis. Nevertheless, it is the qualitative similarity of bivalve assemblages in zones which parallel the coast which should be emphasized as it constitutes the framework upon which statistical variation is superimposed. A shoreface assemblage, a transitional, and an offshore assemblage can be recognized whose dominant species are identical on both lines.

To confirm the qualitative trends discussed above and to provide data on the relative frequency distribution of species smaller than 2.38mm, 300 valves (unbroken and broken) were counted in the biogenic fraction ranging in size from 1.65 to 2.38mm and specific relative frequencies determined for each sample. Figures 55-57 summarize species percentages for locations on lines L1, L2, and RL1. It is evident that general trends in percent distribution established from coarse biogenic material are repeated in the smaller size fraction. The dominant species remain the same except for the addition of diminutive species such as *Crassinella lunulata* and *Nuculana acuta*. However, the proportions of smaller species such as *Ervilia concentrica, Lucina multilineata,* and *Tellina* spp. are increased relative to the larger species. The relict assemblage is not represented in the 1.65 to 2.38mm size fraction.

The detailed bivalve frequency distribution across the limestone outcrop area and on the adjacent sand plain was investigated on line RL1 (Figure 54). The shells of 10 species and genera dominate the bivalve

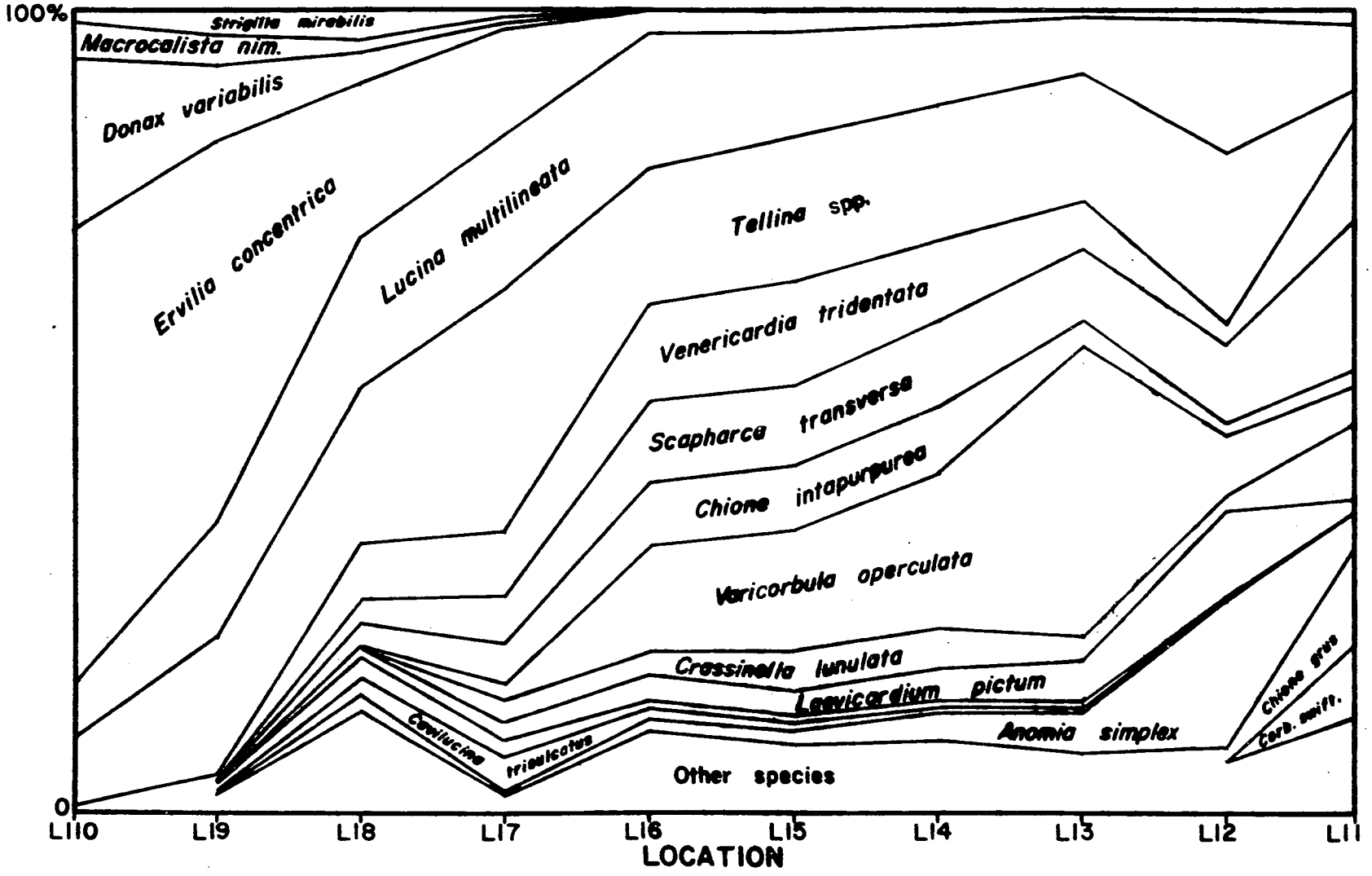


Figure 55. Mean Relative Frequency of Bivalve Species (1.65-2.38mm.) at Locations on Line L1

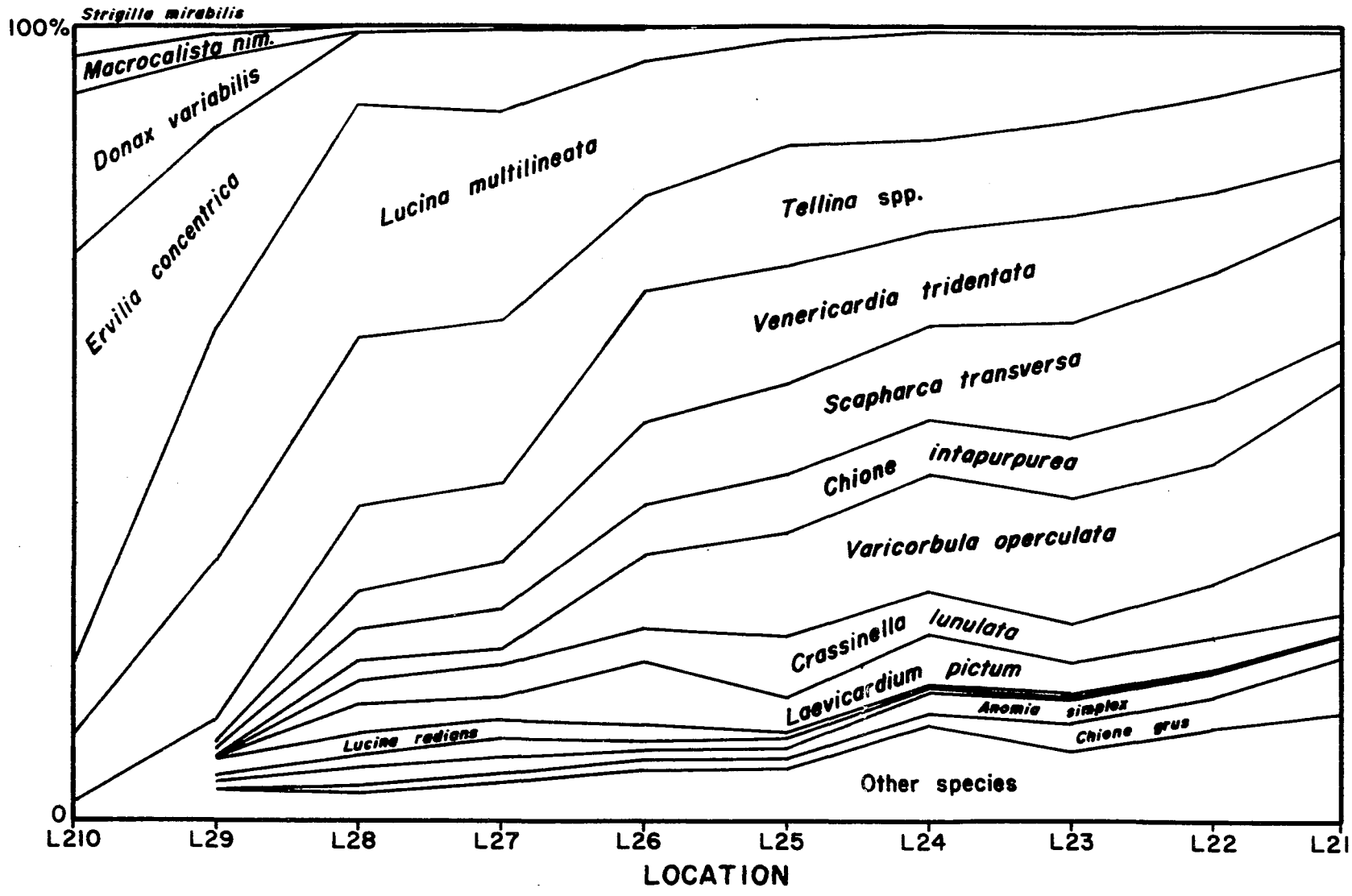


Figure 56. Mean Relative Frequency of Bivalve Species (1.65-2.38mm.) at Locations on Line L2

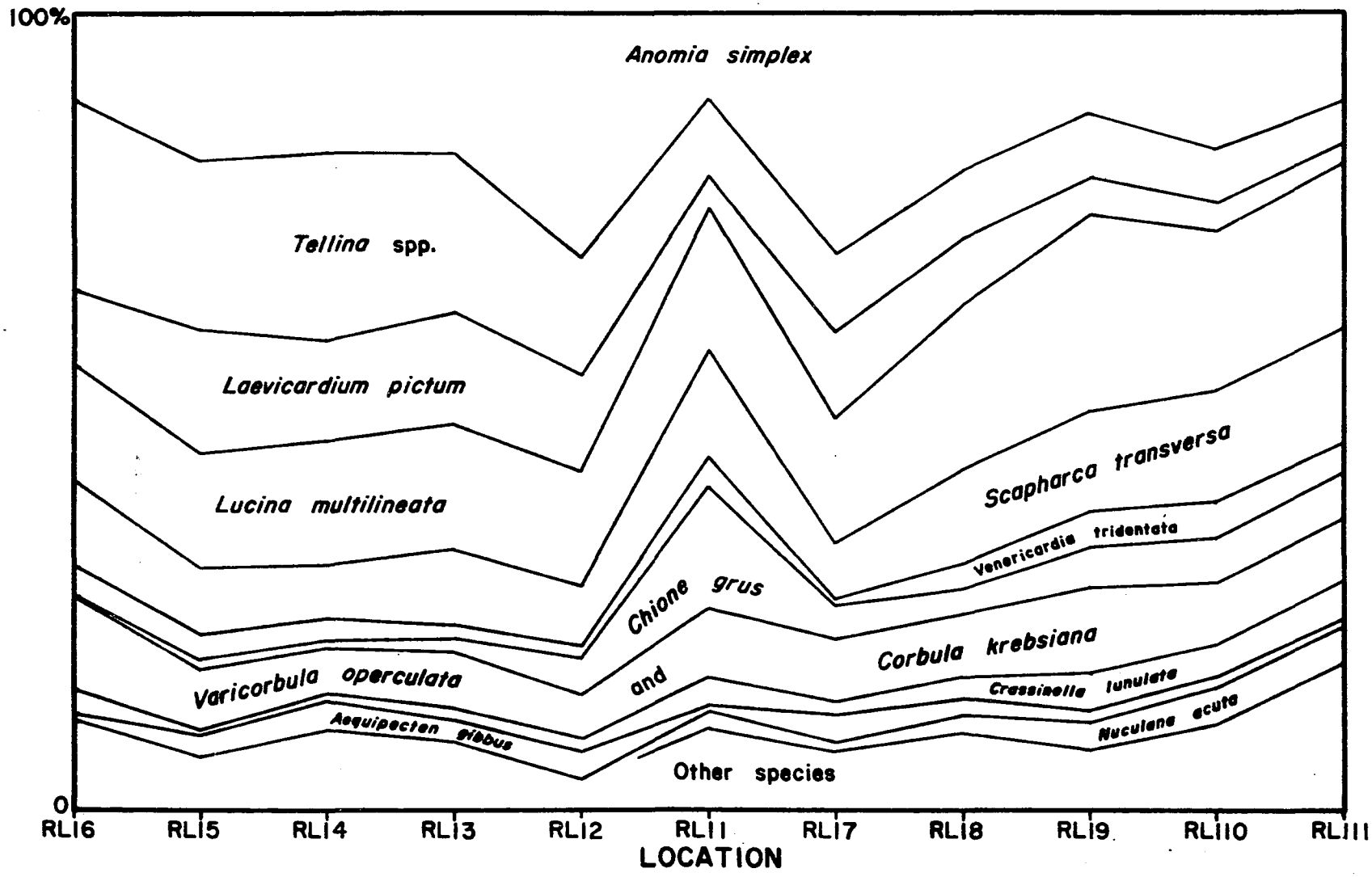


Figure 57. Mean Relative Frequency of Bivalve Species (1.65-2.38mm.) at Locations on Line RL1

thanatocoenosis in the fine sand to the north of the outcrop: *Anomia simplex, Tellina* spp., *Laevicardium pictum, Lucina multilineata, Scapharca transversa, Venericardia tridentata, Chione grus, Varicorbula operculata, Corbula krebsiana,* and *Aequipecten gibbus*. South of the outcrop *Anomia simplex, Tellina* spp., *Laevicardium pictum,* and *Lucina multilineata* are reduced in abundance relative to the increased contribution of relict species, *Scapharca transversa* and *Plicatula gibbosa*. At location RL11, a pocket of sand within the outcrop area, the general distribution is perturbed by a reduction in percentage of *Anomia simplex* shells and other dominant species and a sharp increase in the proportion of *Chione grus* and *Chama congregata* shells in the samples.

The distribution in the thanatocoenosis of the offshore sand plain of bivalve species restricted to or associated with the limestone substrate is important as it relates to the effective transportation and dispersal of the molluscan assemblage. Rock substrate species found in the surrounding sediments are:

Chama congregata	*Arcopsis adamsi*
Arca umbonata	*Arca zebra*
Barbatia domingensis	*Barbatia tenera*
Pteria colymbus	*Lithophaga bisulcata*

Table 7 presents the absolute frequency of these species in semi-quantitative samples in terms of distance from the outcrop along line RL1. Shells of rock substrate species generally occur at their highest frequency at location RL11 within the outcrop area. Frequency of occurrence rapidly diminishes away from the outcrop so that at a maximum distance of 60 feet to the north and south on line RL1 the most distant shells of rock substrate species are found. An exception is one valve of *Pteria colymbus* which was found at a distance of 120 feet to the south (location

	LOCATIONS										
	RL16	RL15	RL14	RL13	RL12	RL11	RL17	RL18	RL19	RL110	RL111
Chama congregata	3	2	7	12	21	53	6	X	X	X	X
Arca umbonata				X	1	4	X	X			
Arca zebra						X	X		X		
Arcopsis adamsi			X	4	6	9					
Barbatia tenera				X	X	2	X				
Barbatia domingensis			X	5	2	8	X	X	X		
Pteria colymbus			X	X	X	X	X		X		X
Lithophaga bisulcata				X							
	120	90	60	30	1	Outcrop Area	1	30	60	90	120

DISTANCE FROM THE LIMESTONE OUTCROP (feet)

Frequency of Shells of Limestone Substrate Bivalves in the Level Bottom Thanatocoenosis on Line RL1. Frequencies shown are within location totals for semiquantitative sample material larger than 2.38mm.

Table 7

RL111). *Chama congregata* is not restricted to the limestone substrate but its frequency of occurrence is clearly influenced by proximity to the outcrop.

Gastropods

The shells of 55 gastropod species were recovered in semiquantitative samples. No attempt was made to treat this group quantitatively, other than a simple tabulation of occurrence, because of the low numbers and irregular distribution of most species. Their frequency of occurrence at locations on lines L1, L2, and RL1 is given in Tables 8 and 9. These figures are the within-location pooled frequencies for each species.

Only a few gastropods are numerically important as contributors of shells to the thanatocoenosis. On the shoreface *Olivella mutica* is a relatively common component of the molluscan assemblage but is rare on the offshore sand plain. *Crepidula fornicata* shells dominate the gastropod assemblage of deeper water. *Terebra dislocata, Cerithium floridanum, Olivella floralia, Oliva sayana,* and *Natica* cf. *N. pusilla* are found consistently but rarely on the shoreface and offshore sand plain.

Near the limestone outcrop increased frequencies of *Calyptraea centralis, Crepidula fornicata, C. plana, C. aculeata, Diodora* spp., and *Olivella floralia* occur which reach their maximum within the outcrop area at location RL11. South of the outcrop, at locations RL17 through RL111, the shells of *Oliva sayana, Cerithium floridanum* are common in the thanatocoenosis as well as relict gastropod species discussed previously.

Scaphopods

The scaphopods are represented by *Dentalium eboreum*. Shells of

LOCATIONS

	L210	L29	L28	L27	L26	L25	L24	L23	L22	L21	L110	L19	L18	L17	L16	L15	L14	L13	L12	L11
Olivella mutica	6	68	10	9	6	2	4	4			37	75	51	32	10	6	2		1	14
Terebra dislocata	1	F	3	2	1	X			5		1	1	2	4	4	5	2	1	X	7
Terebra cinerea	F										F									
Cerithium floridanum	F	F	F	1	F	8	3	8	2	2	F			2	9	9	3	2	1	33
Olivella floralia		1	4	1	4	3	8	X				1	3	5	4	6	2		48	6
Oliva sayana		18	6	F	10	8	9	1	1		1	4	2	3	5	14	F	14	13	F
Crepidula fornicata		2	6	10	22	56	89	83	125	241	1		3	13	27	81	114	176	233	60
Epitonium angulatum			1				X													
Crepidula plana			1	1		2	12	4					1				X		10	6
Terebra concava			1	1	2			4			1	1	2	1		8	X	X		
Natica cf. N. pusilla				2	2	10	8	4	X				2	1	1	2	1		X	X
Polinices duplicatus				F			1		X				1						X	
Conus stearnsi						1	X		X	3			1	F	F	X			F	F
Calyptraea centralis						2		4		16			1				4		72	
Turritella variegata						4		X							F					3
Phalium granulatum						1									2		1			
Marginella succinea							1	X											1	X
Acteon punctostriatus							X										1		X	1
Anachis avera similis								4												
Calliostoma spp.								1												X
Turbo castaneus									F	F										1
Cancellaria conradiana													F		4		X		2	
Conus floridanus															X		F		X	
Strombus (juv.)					1		X	X	X							1	X		F	F
Natica canrena																			F	
Pyrene albella iontha				1	X			1					1			2			8	1
Crepidula aculeata																			4	3
Bulla striata																X	1		F	F
Prunum apicinum																				F
Anachis avera semiplicata																				F
Modulus modulus																				F
Polinices lacteus						1	X		X	X					2			1	1	4
Nassarius vibex										X										F
Nassarius albus																	1		X	F
Epitonium novangliae																				F
Eupleura caudata																				F
Cantharus cancellarius				1			X													F
Rubellatoma diomedia						X	X					1								X
Niso interrupta							3		1						1	X	X		X	
Sinum perspectivum															1				X	
Cerodrillia perryae							1			X				1						
Epitonium multistriatum								X												
Nassarius acutus							X		X										X	X
Diodora cayenensis					1														X	
Dentalium eboreum							X		X	X									28	

X - not present in counted split
F - fragments only

Table 8. Frequency of Gastropod and Scaphopod Species - Lines L1 and L2 (>2.38mm.)

	LOCATIONS										
	RL16	RL15	RL14	RL13	RL12	RL11	RL17	RL18	RL19	RL110	RL111
Oliva sayana	1	F		8	3	9	5	10	37	20	8
Terebra dislocata	1					1	1	X	1	1	5
Cancellaria conradiana	1	1				1	1	1		5	F
Conus floridanus	1					1				8	
Olivella floralia	12	17	6	3	1	33	2	1			X
Cerithium floridanum	F	1		1	1	9	1	28	96	38	68
Calyptraea centralis	25	30	42	48	53	74	4	20	X	X	X
Sinum perspectivum	4	1	9					F	X	X	
Crepidula fornicata	143	124	307	213	141	437	102	151	206	112	80
Atys caribaea	4		1	5							1
Crepidula plana	8	4	15	12	4	27	10	1	25	14	13
Nassarius albus		4		1	3	3	1	9	8	4	2
Polinices duplicatus		X	X			F					
Marginella succinea		4				4					
Natica canrena			1				1				
Crepidula aculeata			4	11	49	57	18	5		X	
Diodora cayenensis			4	5	4	35	4	X		X	
Calliostoma spp.		X		5		8			1		
Pyrene albella iontha		1	1	5	19	1		1	1	4	
Polinices lacteus		2	X	1	4	X	1		1	1	X
Phalium granulatum						F	1		F		
Amaea retifera						1					
Cyphoma gibbosa						2					
Colubraria lanceolata					X	1		X		X	
Cantharus cancellarius		1		2		8		X	26	4	4
Strombus (juv.)				1		1	X	F	2	1	X
Fasiolaria hunteria								F	F		
Melanella intermedia								1			
Crassispira tampaensis								1			
Turbo castaneus						F			47	11	46
Modulus modulus						X		1	59	5	13
Bulla striata		1		1			1		51	5	16
Olivella mutica	X					1			X	12	X
Prunum apicinum						X	X	3	1	6	7
Epitonium angulatum	1	1			1						X
Conus stearnsi						1		X			4
Epitonium novangliae			1	2			1		1	1	
Epitonium apiculatum							1				
Acteon punctostriatus		1			1			1	1	1	
Cerodrillia perryae						X		1		X	
Busycon contrarium									1		
Pyramidella crenulata							X	X	X	X	2
Ithycythera lanceolata			X	1		1		X		1	
Terebra protexta						1					
Turritella variegata						X		X	X		X
Anachis avera semiplicata						X	X		X	1	X
Nassarius acutus				1							X
Eupleura caudata						1					
Dentalium eboreum	35	13	35	2	30		1	6	1	1	1

X - not present in counted split
F - fragments only

Table 9. Frequency of Gastropod and Scaphopod Species - Line RL1 (>2.38mm.)

this large species are frequently encountered in the fine sand north of the limestone but rarely elsewhere (see Tables 8 and 9).

Biologic Sediment Modification

Many macroinvertebrate species contribute to sediment modification in the research area. The activities of these organisms are recorded in the sediment as a complex array of burrows, tubular structures, resting traces, and feeding and locomotory trails. The morphology, origin, and nomenclature of biogenic sedimentary structures have been reviewed by Seilacher (1964) and Schafer (1972). The invertebrate groups responsible for sediment modification in the study area are discussed below.

Echinoderms

The echinoderms are most important in the bioturbation of surficial sediments of the lower shoreface and offshore sand plain. *Plagiobrissus grandis* burrows in an anterior direction about 2 to 3 inches below the surface by movement of spoon-shaped ventral and lateral spines. Forward motion of *P. grandis* probably produces a subsurface trail of homogenized sediment or cresentic fill structures similar to those described by Schafer (1972) for *Echinocardium*. *Plagiobrissus grandis* maintains an open burrow with long dorsal spines which prevent its collapse. Kerr and Grant (1965) describe depressed surface trails which mark the forward progres of the animal but no such trails were observed in the study area. When exposed, *P. grandis* is able to bury itself rapidly by coordinated movement of ventral and lateral spines which produces a ring of excavated sand which gradually covers the urchin as it sinks below the surface.

The surface expression of its activities is a conical depression at the base of which the tips of the dorsal spines are usually visible. Where *P. grandis* is abundant the sea floor is much disturbed by closely spaced depressions.

Encope michelini, E. aberrans, and *Mellita quinquiesperforata* have similar feeding habits, methods of locomotion, and shape and produce similar trails. These sand dollars burrow horizontally through the upper surface of the sand and are often clearly visible by the sand covered outline of the test. Their forward motion is accomplished by movement of ventral and peripheral ambulatory spines which are concentrated in interambulacral areas (Kier and Grant, 1965). The trails of these animals are flat, shallow depressions, the width of the test, which intersect in random patterns on the sea floor. These surficial modifications are easily destroyed by wave-induced currents. Nevertheless, where abundant, the activity of these echinoids is an important mechanism in reduction and elimination of bed forms and microtopography.

The asteroids are of minor importance in terms of bioturbation. Five-rayed resting or digging traces are commonly observed but the activities of these epibenthic organisms are usually confined to the sediment surface.

Mollusks

The sparse nature of molluscan assemblages in the research area suggests that this group is relatively unimportant in biologic sediment modification. Suspension feeders, which include most bivalve species of the level bottom, are sedentary burrowers and usually move only in response to some external stress. Although strong burrowing suspension

feeders such as *Macrocallista nimbosa*, *Spisula solidimissa*, and *Dinocardium robustum* are present in the study area, they are rare and confine their burrows to the uppermost sediment layers. Abandoned burrows appear as poorly defined areas of disturbed sediment.

The deposit feeding bivalves, typified by members of the Tellinidae, are rarely found in the coarser sands but are encountered consistently, in qualitative samples, in the fine sand north of the limestone outcrop. According to Schafer (1972) these bivalves move forward through the sediment as deposits of organic material within reach of their inhalent siphons are depleted. Pseudofeces consisting of vermicular castings are ejected by the inhalent siphon and are commonly observed on the fine sand substrate. The burrowing of this group may be of local significance in the bioturbation of the surface layers.

The vagile endobenthic gastropods *Oliva sayana*, *Olivella mutica*, *Terebra dislocata*, *Polinices duplicatus*, and *Sinum perspectivum* produce linear sag trails which mark the path of the organisms in the surface sediments. *Oliva* and *Terebra* are distinguished by narrow, sharp depressions as they advance by pedal contractions with inhalent siphon extended above the sand. *Polinices* and *Sinum* move forward by extension, expansion, and contraction of the large propodium which covers the head and nearly all of the shell. Trails of these gastropods are broader and less well defined. The sea floor is often densely reticulated by the locomotory trails of these common species.

Polychaetes

Three modes of burrowing behavior can be distinguished among the polychaetes: 1) free burrowing, 2) mucous tube dwelling, and 3) agglu-

tinated tube dwelling.

Free Burrowers

Nephtys picta

Mucous Tube Dwellers

Lumbrineris inflata
**Ceratonereis irritabilis*
**Sthenelais articulata*
**Glycera* aff. *G. tenuis*
**Arabella iricola*
**Drilonereis* sp.
**Glycera americana*
**Notomastus hemipodus*

Agglutinated Tube Dwellers

Onuphis magna
Onuphis quadricuspis
Cistenides gouldii
Clymenella torquata calida
Chaetopterus variopedatus
Onuphis eremita oculata
Diopatra cuprea cuprea
Megalomma lobiferum
Axiothella mucosa
**Polydontes* aff. *P. maxillosus*

*questionable life habits

Unknown Habits

Lepidametria commensalis
Chloeia viridis
Aricidea jeffreysi

Nephtys picta is a common nearshore free-living polychaete which burrows through the upper 10 to 12cm of sediment in search of food. The magnitude of sediment disturbance by this and similar species must be considerable in surface sediments.

The most common of the mucous tube dwelling polychaetes is *Lumbrineris inflata* which is extremely abundant on the shoreface and inner offshore sand plain. Populations of this small worm produce closely spaced vertical mucous-lined burrows which sometimes bifurcate but terminate at a depth of 10 to 12cm. The effect of these tubes is to alter sediment texture by binding sand grains in a cohesive, soft mucous matrix. The presence of *Lumbrineris inflata* and other species of mucous-secreting polychaetes is therefore important not only in reworking the

upper sediment layers but also in altering the mechanical properties of the sediment.

Most of the larger polychaetes collected in the research area inhabit strongly agglutinated tubes. These may penetrate the sediment to considerable depth, as in the case of *Onuphis magna,* or may be relatively shallow structures. The dwelling tubes of *Onuphis magna* reflect the large size of this species; they are generally 10mm in diameter and at least 40cm in length. The tubes are oriented vertically in the sediment and project 1 to 2 inches above the surface. They are composed predominantly of a tough, elastic substance which incorporates scattered shell fragments and quartz grains. Small aggregations of *O. magna* are widely scattered on the lower shoreface and offshore sand plain frequently associated with the sabellid *Megalomma lobiferum.* Other tubiculous species are rare on the level bottom except near the limestone outcrop.

In the fine sand north of the outcrop a diverse assemblage of tubicuous polychaetes is developed which includes as the most abundant forms *Diopatra cuprea cuprea* and *Onuphis eremita oculata. Diopatra cuprea* tubes are about 14cm in length and consist of single vertical agglutinated structures, closed at the lower end, with the openings slightly elevated above the sediment surface. The upper portion of the tube is constructed of shell fragments oriented horizontally while the lower portion is constructed of agglutinated fine quartz sand. *Diopatra cuprea* individuals are dispersed in uniform densities of 4 per square foot.

Onuphis eremita oculata tubes are evenly constructed of agglutinated quartz grains and small shell fragments, arranged tangential to the

tube surface. They are narrow and straight -- 3mm in diameter and 14 to 16cm in length. The tubes are often anchored to buried shell or other large debris. *Onuphis eremita* is densely distributed in the sediment, approaching 50 individuals per square foot.

Where they are abundant, as in the above setting, strongly agglutinated polychaete tubes provide mechanical support for the surrounding sediment thereby inhibiting its erosion. This mechanism was advanced as an explanation for the continued presence of the anomalous fine sand body in a regime of general landward sediment transport. Tubes which project even slightly above the sediment surface may act as baffles and sediment traps in a manner similar to that described for the sea grass *Thallassia* by Ginsberg and Lowenstam (1958).

The activities of tube dwelling polychaetes, through continual establishment of new burrows and abandonment of old, intensively rework and homogenize upper sediment layers. Their high densities, particularly in finer sands, suggests that they are of primary importance in terms of bioturbation.

Crustaceans

Of the many species of crustaceans noted in the study area *Callianassa* spp., abundant in the nearshore faunal zone, is most vigorous in its subsurface excavation. The method and pattern of burrowing are well known. *Callianassa* begins burrowing by moving sand backwards with the enlarged claw of the first pair of walking limbs aided by the other appendages (Schafer, 1972). A burrow 20 to 30cm deep is constructed consisting of a number of branching lateral tunnels connected to the surface by several vertical or inclined entrance tubes. The burrows are

strengthened by pellets of mucous-coated sand which are pressed into the walls. Continued burrowing by *Callianassa* results in the growth of conical mounds of ejected sand at burrow entrances. Wave agitation is such in the nearshore zone that mounds do not form; sand is redistributed as fast as it can be accumulated. Entrances therefore consist of a slight projection of the mucous-strengthened burrow lining above the otherwise flat or rippled sand bottom. Frequent erosion of the shoreface during storms exposes the abandoned subsurface burrow systems. The observed density of *Callinassa* surface entrances and subsurface burrows indicates the efficacy of *Callianassa* in the bioturbation of nearshore sands.

Enteropneusts

The enteropneust *Balanoglossus* sp., abundant on the shoreface, inhabits a deep U-shaped burrow. Several conical depressions or collecting pits (Schafer, 1972) form the anterior vertical limb of the burrow and conduct sediment and organic material to the animal which lies at the base of the U. Sediment, from which organic material has been digested, is extruded at the posterior end of the burrow to form a conical mound of vermicular castings. As new collecting pits are established the surrounding sediment is completely reworked. The shoreface sands are intensely disturbed by the depressions and mounds of *Balanoglossus* and its subsurface burrows.

Vertebrates

Several species of fish were observed to burrow rapidly into the sediment for protection when approached. One species is quite common and

constructs nests of coarse shell material when such fragments are available. Often the only concentrations of shells are found in the nests of this fish. Other fish, such as rays, flounders, and many other unidentified species, rest in the uppermost sand layers. The feeding excavations of large rays are rarely seen, the largest measuring 3 feet across and 1.5 feet deep.

Discussion

The movement of organisms through and over the sediment creates disturbances which obscure primary sedimentary structure. Some types of biologic activity tend to homogenize the sediment. In other cases sediment components are reordered in structures which reflect the form and function of the organisms involved. The mechanisms and sedimentologic consequences of bioturbation have been discussed by Hanor and Marshall (1971). They recognized four processes whereby sediment components may be biologically reordered and disordered: 1) Turbulent diffusion -- sediment mixing in eddies around the margins of organisms, 2) Shear -- distortion of the sediment without turbulence, 3) Advection -- bulk transport of sediment, 4) Molecular diffusion and chemical reaction.

Turbulent diffusion is the most commonly observed mechanism for sediment mixing in the study area. Most of the vagile or conditionally vagile invertebrates referred to previously disturb the surface sediments through simple displacement and stirring of the adjacent sand. Shear, as a distinct process, probably does not occur in these loose sands where turbulence and eddy formation are favored. Most bioturbation is accompanied by small-scale advection but significant transport of sediment is accomplished primarily by *Callianassa* sp. and *Balanoglossus* sp. *Calli-*

anassa continually brings subsurface sand to the surface as it constructs its burrow. *Balanglossus*, through ingestion and excretion of near-surface sediment, achieves both lateral and vertical advection. When burrow systems are abandoned surface sediment often infiltrates and fills them or they collapse; both are forms of advection.

The burrowed sea floor is characterized by a mottled appearance. Recent surface disturbances are recognized as light colored patches of sand on an otherwise darker bottom. The dark color of undisturbed sand in the research area is a result of a surface film of organic material, presumably composed of benthic diatoms and accumulated organic debris. Mottling occurs when the organic material is removed from the surface by simple disturbance, or deposit feeding, or advection of non-organic sands from the subsurface.

Mottling of another type is found in the nearshore zone where *Callianassa* is abundant. Where erosion has exposed previously buried portions of burrow systems an aureole of white, oxidized sand is observed around each tunnel. The burrow systems act as conduits for oxygenated water which enters the sediment and oxydizes the included organics. Advection of surface sand into abandoned burrows enhances the mottled appearance of the subsurface sands.

PALEOECOLOGIC CONSIDERATIONS

Life and Death Assemblages - Comparisons

The thanatocoenosis represents the long-term response of biogenic material to the physical and biological environment. Transitory phenomena, such as population aggregations or seasonal fluctuations in density, may not be reflected in the death assemblage as these effects are averaged over time (Warme, 1969). Conclusions concerning the relationship between the thanatocoenosis and living community based on short-term observations of clumped or sparse populations must be presented as speculative. Nevertheless, general patterns of biotic distribution can be effectively evaluated in terms of post-mortem modification of community composition.

Soft-bodied organisms, such as the polychaete worms, *Balanoglossus* sp., and many species of the limestone substrate, although abundant in the living fauna, are not represented in biogenic accumulations. To the extent to which these species are dominant the thanatocoenosis is not an adequate reflection of the community. Other groups, including crustaceans, asteroids, sponges, and alcyonarians, are either weakly calcified or produce skeletal elements which are too small to be retained on the sampling screen.

General Components

Organisms which produce coarse skeletal material are represented in the death assemblage in the frequency rank in which they occur in the living community. Bivalves, as the most abundant living group, comprise most of the biogenic grains when fragments and valves are considered

together. The absence of general trends in bivalve shell distribution either between traverse lines L1 and L2 or between locations suggests that differences in living population density noted between these two lines are short-term or seasonal variations in standing crop which are of little influence on the overall composition of the thanatocoenosis. The trend of decreasing unbroken and broken bivalve shell percentages in a seaward direction on line L2 is attributable to an increase in the degree or rate of fragmentation in that direction. The constant percentage found on line L1 results from a decrease in fragmentation seaward from location L15 to L12.

The low percentage of gastropod shells and fragments parallels the low frequency of this group in the living community. Observation and sampling indicate an extremely sparse and dispersed population of living gastropods which evidently contributes a uniform proportion of shells to the thanatocoenosis when percentage is averaged over locations and traverse lines. The increase in relative frequency at shoreward locations on line L1 is due to an increase in *Olivella mutica* shells.

Encope spp., as a widespread and abundant member of the living community, is well represented as the second most abundant grain type. *Encope* fragments decline in relative frequency with increasing distance from shore and depth at locations on lines L1 and L2. Census of the living *Encope* population show a decline in adult *Encope* density towards the seaward end of line L1. This trend accords with observations of low *Encope* density at other deeper water locations in the study area and on the adjacent shelf and with observations of Kier and Grant (1965) who recorded *E. michelini* at Key Largo to maximum depths of 20 feet. However, juvenile populations found on line L2 have a maximum density at location

L25 on the offshore sand plain. Possibly, the distribution of adult populations on line L1 is more representative of long-term distribution patterns while juvenile population densities and distributions reflect random within-habitat larval colonization. In any case, high juvenile densities do not significantly increase the relative frequency of *Encope* spp. fragments in semiquantitative samples even though mortality is probably high judging from adult densities. Juvenile tests are fragile and easily comminuted to small fragments which are not retained on the 2.38mm sampling screen. Relative frequencies of *Encope* spp. fragments therefore largely reflect adult population distributions.

Plagiobrissus grandis, only locally abundant, is of secondary importance as fragmental debris in the death assemblage. The observed difference in relative frequency of *Plagiobrissus grandis* fragments between lines L1 and L2 can be explained in terms of shifting population aggregations and continual destruction of *P. grandis* fragmental material by mechanical processes. No living populations of *P. grandis* were found at locations on line L1 whereas dense juvenile populations were noted on line L2. High juvenile mortality was noted in these populations but fragments of these tests did not appear in the samples. As in the case of juvenile *Encope* spp., the extremely fragile tests were crushed to fragments finer than the mesh size of the sampling screen. *P. grandis* fragments found in samples therefore represent, for the most part, adult specimens. The paucity of fragments on line L2 as compared with line L1 is probably due to the extremely clumped nature of *P. grandis* population distributions. Adult individuals contribute test fragments to the thanatocoenosis wherever *P. grandis* populations mature. These areas are thereafter abandoned while larvae colonize other local areas of the sea

floor. The fragments contributed by adult individuals continue to be comminuted by mechanical and biological reworking due to their fragile nature, resulting in a reduced relative frequency of *P. grandis* fragments in the samples. The relatively high percentage of fragments on line L1 may therefore indicate recent abandonment of this area by adult populations while the low percentage of fragments on line L2 may reflect a more remote colonization and abandonment.

The distribution of the coralline alga *Neogoniolithon* sp. in the living biota is reflected in the distribution of abundant fragments in deeper water at the seaward ends of lines L1 and L2. The precise depth range of this species is unknown for the study area so that the effect of landward transport on the distribution of this species in the death assemblage cannot be ascertained. It is probable that the rare landward occurrences of *Neogoniolithon* sp. fragments represent transported material. Colonies of the bryozoan *Discoporella umbellata* are also distributed in the sediment in accordance with their depth distribution in life.

Changes in relative frequency distributions of major grain types at locations on line RL1 are difficult to interpret in terms of the living community. The level bottom community adjacent to the outcrop (location RL11) does not include *Plagiobrissus grandis* or *Encope* spp. Substrate conditions appear to be unfavorable for these burrowers. South of the outcrop very coarse-grained sediments contain rock fragments and much large shell debris which presumably inhibit burrowing and feeding by these species. To the north, the fine-grained sand is tightly bound by tubiculous polychaetes which makes burrowing difficult for large organisms such as *P. grandis* and *Encope* spp. However, whole *Encope* spp. tests are

common near and within the outcrop area; they are deeply etched and appear to be very old. Presumably, fragments in the thanatocoenosis are in part derived from these older tests. The possibility remains that populations of *P. grandis* and *Encope* spp. have become established from time to time in this area in spite of the seemingly adverse conditions. This assertion is supported by the abundance of large *P. grandis* fragments north of the outcrop which clearly cannot survive long periods of exposure and transport.

The reduction in relative frequency of *P. grandis* and *Encope* spp. south of the limestone outcrop may be related to a combination of 1) selective destruction of their fragments, a topic to be developed more fully later, 2) relative increase of molluscan fragments and shells contributed by the relict assemblage, 3) increase in production of *Neogoniolithon* sp. The decline in bivalve shell (unbroken and broken) percentage to the south is also probably controlled by these factors. Increased relative abundance of coralline algae noted at location RL11 does not appear, from observation, to reflect increased production but rather possible derivation of fragments from the erosion of the limestone. A more detailed examination of the area is needed to confirm this conclusion. Fragments of coral, primarily *Phyllangia americana* and *Astrangia astreiformis,* are restricted in occurrence to locations immediately adjacent to the outcrop indicating only minor transport of recognizable coarse fragments.

Mollusks

The relative frequency distribution of molluscan species of the thanatocoenosis can be compared only in general terms to living molluscan

populations because of incompletely known distribution patterns of living species in the research area. Published accounts of regional species habitats are clearly inadequate, from this writers experience, to provide a basis for precise evaluation of the thanatocoenosis in terms of transportation. However, it is possible to answer the more general and perhaps more pertinent question: does the molluscan thanatocoenosis of the level bottom form a basis for the reconstruction of the community?

Bivalves

Living bivalve species of the level bottom are, without exception, represented in the thanatocoenosis. The more common members of the living community include some of those which also occur abundantly in the death assemblage. *Cavilucina trisulcatus*, *Lucina radians*, and *Tellina* spp., collected alive on the shoreface and offshore sand plain, are found in the thanatocoenosis of both zones. *Venericardia tridentata*, *Crassinella lunulata*, *Laevicardium pictum*, and *Chione intapurpurea*, frequently occurring and widely distributed species in the molluscan community of the offshore sand plain, are found in abundance as dead shells there.

However, many abundant species of the death assemblage are represented only rarely in the living fauna: *Scapharca transversa*, *Anomia simplex*, *Varicorbula operculata*, *Corbula krebsiana*, *Pandora trilineata*, *Ervilia concentrica*, *Stigilla mirabilis*, and *Macrocallista nimbosa*. The rarity of these species in collections of living biota as opposed to their abundance as dead shells probably reflects inadequate sampling of living populations and accumulation of shells of these species over a long time period. Other abundant species of the thanatocoenosis, such as *Lucina multilineata* and *Donax variabilis*, were not collected alive in any semi-

quantitative samples. Fresh shells and published ranges of *L. multilineata* suggest that this species is a member of the living community.

Donax variabilis, abundant as empty shells on the shoreface, is restricted in life to the narrow surf-dominated coastal zone. Shells of *D. variabilis*, aside from those of the relict assemblage, are found as far as 2600 feet from shore at location L16 (depth 59 feet). Their occurrence on the shoreface probably represents an accumulation of transported shells. Likewise, rare occurrences of *Spisula solidissima* in lower shoreface assemblages may indicate downslope transport. The possible seaward transport of other shoreface species cannot be assessed because of less well defined depth ranges.

Thirty-five species rarely found alive on the offshore sand plain are also rare in the thanatocoenosis. Their distributions as living individuals and dead shells are in reasonable agreement. *Plicatula gibbosa* lives cemented to coarse shell material south of the limestone outcrop and is most common in biogenic accumulations there. *Corbula swiftiana* and *C. barrattiana* are found alive and as dead shells only near the outcrop. *Lucina nassula* is most frequent in both the living community and the thanatocoenosis in the fine sands to the north of that feature. One specimen of *Venericardia perplana* was taken alive at location L11 south of the outcrop where this species occurs in bivalve shell assemblages. Other rare members of the living community are more dispersed in distribution.

The remaining 62 less common bivalve species of the level bottom thanatocoenosis without living representatives are compatible in distribution with published records of living continental shelf assemblages, with the exception of rock substrate and relict species.

Detailed investigation of bivalve assemblages on line RL demonstrates the relationship between composition of the thanatocoenosis and proximity to the outcrop and its biota. The Arcidae of the rock substrate (see page 165) are byssally attached bivalves whose shells become available for transport upon disintegration of the byssus after death. Many empty shells of these species, particularly *Arca umbonata* and *Barbatia domingensis*, are observed on the sea floor among the limestone blocks. The Chamidae, represented most abundantly by *Chama congregata*, are cemented by the left valve to the rock substrate. Upon death, right valves are easily disarticulated and accumulate in the sediment. It is evident from Table 7 that, although transportation of shells of these species is occurring, the contribution of limestone substrate species to the level bottom thanatocoenosis has little influence on its composition except immediately adjacent to the rock and within the outcrop area where pockets of sand exist. At more distant locations the character of the death assemblage is determined by the present assemblage of the offshore sand plain and, south of the outcrop, the relict molluscan assemblage.

At location RL11 (Figures 54 and 57) increased relative frequencies of *Chama congregata, Chione grus, Scapharca transversa*, and other arcids are encountered which reflect populations of these epibenthic species in the limestone substrate community.

Gastropods

The most common gastropod species of the level bottom thanatocoenosis are those which are also commonly observed alive: *Terebra dislocata, Oliva sayana, Olivella mutica, Crepidula fornicata, Natica* cf. *N. pusilla*. The distribution of *Olivella mutica* shells parallels its

common occurrence in the shoreface molluscan community. *Terebra dislocata*, *Oliva sayana*, and *Natica* cf. *N. pusilla*, widespread living gastropod species on both the shoreface and offshore sand plain, are commonly found as dead shells throughout the study area. *Crepidula fornicata* occurs alive wherever suitable substrate is available.

The occurrence and abundance of *Crepidula aculeata*, *C. plana*, *C. fornicata*, *Calyptraea centralis*, *Cyphoma gibbosa*, *Diodora* spp., and *Calliostoma euglyptum* as members of the limestone substrate community are reflected in increased frequencies of these shells at locations on line RL1 near the outcrop. Since these gastropods require firm substrate, occurrences in the level bottom thanatocoenosis possibly represent transported shells. However, coarse shell debris is known to support the Calyptraeidae so that their presence does not necessitate transportation. *Diodora* spp. and *Calliostoma euglyptum* shells occur at distances from the outcrop similar to those found for arcid bivalves, indicating a similar magnitude of transport.

No living *Cerithium floridanum* or *Olivella floralia* were found in the study area even though these species were common as dead shells. *Cerithium floridanum* was taken alive in Choctawhatchee Bay and is described by Perry and Schwengle (1955) as ranging from low tide to 5 fathoms. Many of the shells and fragments of this species are worn. These facts, and its occurrence in increased frequency south of the outcrop where relict mollusk shells are common, suggests that *C. floridanum* may be a member of that group. *Olivella floralia* is reported to be a common open Gulf shallow water species; small size and rare occurrence in the living community in the study area presumably account for its absence in collections.

Other gastropod species are too rare either alive or dead to be of interest in this discussion.

Scaphopods

Dentalium eboreum is frequently found both alive and as empty shells north of the outcrop where the fine sand is favorable for this detritus feeder. Shells of *D. eboreum* are very rare elsewhere.

Summary

Molluscan species are distributed in zones which parallel the coast both as empty shells and as a living community. The shoreface faunal zone, characterized by living *Ervilia concentrica, Strigilla mirabilis, Macrocallista nimbosa,* and *Olivella mutica,* is also defined by high frequencies of these species in the shoreface thanatocoenosis. The offshore sand plain faunal zone is represented in both the life and death assemblage by a more diverse molluscan association including as common species *Venericardia tridentata, Crassinella lunulata, Laevicardium pictum,* and *Chione intapurpurea.* Other common species of the offshore sand plain thanatocoenosis are only rarely represented by living individuals. A transitional zone between these two major divisions is recognized in the death assemblage by the increased relative abundance of *Cavilucina trisulcatus, Lucina radians,* and *Pandora trilineata.* In the living community *Cavilucina trisulcatus* and *Lucina radians* are consistent in occurrence on both the shoreface and offshore sand plain while only one specimen of *Pandora trilineata* was taken. Apparently, collections of living bivalves were insufficient to delineate the transition zone found in the composition of shell accumulations. Other common and rare species

of the thanatocoenosis are in general agreement with the distribution of their living representatives wherever they occur. The inference is made that the distribution and relative frequency of occurrence of molluscan species in the death assemblage adequately reflects the long-term composition and distribution of the molluscan community, with the exception of occurrences of *Donax variabilis* and relict molluscan species.

The abundance of *Donax variabilis* on the lower shoreface indicates considerable downslope transport of shell material. However, transport of shell material on the offshore sand plain appears to have little influence on the composition of the thanatocoenosis, judging from investigation near the limestone outcrop.

The general composition and distribution of major grain types is related primarily to trends in life distributions of those groups and secondarily to selective preservation.

Recurrent Bivalve Associations

The composition of the living community is often inferred from recurrent associations of fossil species under the assumption that species which lived together have a higher probability of occurring together in the thanatocoenosis than species which lived apart. The effects of transportation and other post-mortem assemblage alteration was presumed, in this view, to have little systematic influence on assemblage composition as compared to the effect of ecologic factors (Johnson, 1962b). Statistical methods for evaluation of recurrent association on a presence-or-absence basis have been reviewed by Cole (1949), Fager (1957), and Johnson (1962b). Since much paleontologic data are of a presence-or-

absence nature, it is of interest to evaluate the thanatocoenosis of the research area in terms of recurrent association to determine if patterns of species occurrence adequately reflect the distribution of living biota.

The significance of bivalve species associations in the thanatocoenosis was evaluated with the chi-square test for goodness-of-fit. Two by two contingency tables were prepared for 6120 possible species pairs (Appendix F). Each table represented the joint occurrences, the joint absences, and exclusive presence and absence of the species in the pair under investigation. An occurrence was determined as the presence of a species in any of the semiquantitative samples within location; a total of 31 locations yielded 31 possible occurrences. The chi-square statistic tested the null hypothesis of independence of occurrence against the alternate hypothesis that the occurrence of the two species was not independent. The probability of obtaining the observed chi-square under the null hypothesis was determined by reference to standard one-tailed chi-square tables.

The chi-square test is not appropriate when the expected value of any cell of the contingency table is less than 5. This occurred with the data at hand when more than one cell had a measured value of 0. Forty-seven bivalve species in the death assemblage were too rare in occurrence to be evaluated with the chi-square statistic. These primarily included relict species and limestone substrate bivalves. The chi-square test was performed for the remaining 65 bivalve species of the level bottom.

Recurrent associations of bivalve species were determined on the basis of calculated chi-square values. Species pairs were considered to be bonded when the probability of independent occurrence was very low. A level of significance of .005 (chi-square $\geq$ 6.63) was selected to yield

well-defined groups of interbonded species. Johnson (1962b) and Fager (1957) also found that a significance level of .005 was most appropriate for the definition of association. Bonded species were subjectively grouped into associations according to the number of shared bonds within the group. For this purpose only those species which were bonded to at least five other species were considered initially. Twenty-seven species were associated at the .005 significance level with five or more other species. These formed two well-defined bonded associations which shared only 9 intergroup bonds.

I	II
Abra aequalis	*Pecten muscosus*
Chama congregata	*Pecten raveneli*
Corbula krebsiana	*Parvilucina amiantus*
Varicorbula operculata	*Diplodonta punctatus*
Diplodonta nucleiformis	*Tellina alternata*
Gouldia cerina	*Cuspidaria ornatissima*
Laevicardium laevigatum	*Corbula dietziana*
Macrocallista maculata	*Corbula barrattiana*
Crassinella lunulata	*Ensitellops protexta*
Semele bellastriata	*Glycymeris pectinata*
Nucula proxima	*Anodontia alba*
Nuculana acuta	
Plicatula gibbosa	
Transennella sp.	
Tellina interrupta	
Verticordia ornata	
Lucina nassula	

Erycina floridana occupied an intermediate position between these distinct associations being well bonded to both groups. A third association was discovered when species with less than five bonds were considered. This group consisted of the bonded pair *Donax variabilis-Macrocallista nimbosa*. These two species displayed highly significant negative association with 9 species of the above groups. Although calculated chi-square values were large (therefore suggesting non-independence of occurrence with members of groups I and II), the values arose from the almost complete absence of

associated occurrence rather than joint occurrence of species pairs. Other bivalve species of the level bottom which shared less than five bonds entered group I or II.

I	II
Aequipecten gibbus	*Atrina serrata*
Pandora trilineata	*Scapharca transversa*
Pandora arenosa	*Abra nuculoidea*
Ensis minor	
Anadara ovalis (juv.)	
Corbula swiftiana	
Tellina lintea	
Ervilia concentrica	
Lucina pensylvanica	
Eucrassitella speciosa	

However, the assignment of those species to groups I and II was somewhat ambiguous since they were associated with so few species at the .005 significance level.

The most commonly occurring and abundant species of the thanatocoenosis constitute most of those which showed no significant association ($p \leq .005$) with other bivalve species. These include: *Anomia simplex, Chione grus, Chione intapurpurea, Laevicardium pictum, Lucina multilineata, Lucina radians, Cavilucina trisulcatus, Venericardia tridentata* and the less common species *Anatina lineata, Chione cancellata, Dinocardium robustum, Montecuta floridana,* and *Cooperella atlantica.* The lack of joint absences for species pairs containing the above bivalves led to acceptance of the hypothesis of independence since most of these species occurred at virtually all 31 locations. *Cooperella atlantica* was an exception in its rare and apparently random distribution with respect to other bivalve species.

Groups I and II include species of the lower shoreface and offshore sand plain. An examination of Figures 48-50 shows that species of group

I recur throughout that broad zone. In contrast, group II species are restricted in occurrence primarily to locations in water depths greater than 60 feet near the seaward ends of lines L1 and L2 and in particular near the outcrop. Group III, consisting of *Donax variabilis* and *Macrocallista nimbosa*, is characteristic of the shoreface thanatocoenosis.

It is evident that recurrent bivalve associations are defined in large part by the occurrence of species of low relative frequency in the above analyses. These species are correspondingly very rare in the living community with unknown distributions. It is difficult, therefore, to make any definite statement concerning the relationship of recurrent species groups in the death assemblage to life distributions. There is no evidence from qualitative or semiquantitative samples to suggest that shells of groups I and II do not reflect contributions by indigenous bivalve species; a depth-related subdivision of the offshore sand plain bivalve community would be possible if biotic distributions were more completely known. Rare occurrences of living representatives of group I and group II species are found within their respective ranges in the thanatocoenosis (see Table 3). On the other hand, group III is clearly a spurious association of indigenous *Macrocallista nimbosa* shells and transported *Donax variabilis* shells.

Species of the relict assemblage and the limestone substrate community appear to form coherent recurrent associations in the death assemblage although this observation was not verified statistically (see Figures 52 and 54). As previously proposed, the relict assemblage is possibly a composite association of shells derived from a series of Early Holocene communities. Their recurrent association in the death assemblage does not reflect an association in life.

It is clear that ecology is not, in all cases, the overriding control of species occurrence in the research area. Significant associations may merely reflect post-mortem events which brought together the remains of species which were separated in both time and space as members of a living community. However, the associations defined for most members of the level bottom thanatocoenosis agree with the limited data available concerning their distribution in the living community.

Preservation

Three modes of fossil preservation have received attention in the literature as possible indicators of shell transport: 1) fragmentation, 2) shell surface condition, 3) selective preservation.

Johnson (1960) reviewed criteria for determination of transported assemblages and concluded that fragmentation was an important indicator of prolonged exposure and transportation. Johnson (1962) reiterated this relationship but concluded that, for Pleistocene fossils of the Millerton Formation, "disassociation, fragmentation, and wear are features affected by exposure with or without transportation." In his review of preburial alteration of fossil assemblages Fagerstrom (1964) also found that "neither the surface condition of fossils nor the ratio of whole to fragmented shells can be used with much certainty in determining the mode of formation of fossil assemblages." Fagerstrom stressed the importance of scavengers and predators as agents of fragmentation. Warme (1972) attributed fragmentation in Mugu Lagoon to the activities of predators but found that post-depositional deterioration of shells also took place by dissolution.

Selective preservation reflects differences in shell architecture including fundamental microstructure, thickness, and size. Schafer (1972) emphasized the role of mechanical abrasion and wave agitation in the destruction and selection of skeletal debris. Johnson (1960) recognized the importance of selective preservation of robust biogenic material in the death assemblage. In addition to the general shape and thickness of the shell, Taylor and Layman (1972) demonstrated that differences in bivalve shell strength are related to the size of the microstructural units.

Selective transport or destruction of small shells has been inferred by many workers (Fagerstrom, 1964; Johnson, 1960, 1962; Boucot, 1953; and Olson, 1957) to be an important mechanism in environments which favor transport. Right-skewed size frequency distribution curves, a result of high juvenile mortality, become gaussian as small shells are selectively removed from the assemblage. However, Craig and Hallam (1963), Craig and Oertel (1966), Hallam (1967), and Craig (1967) demonstrated that size frequency distribution in bivalve shell accumulations is controlled primarily by growth rate, and that juvenile mortality is not as high as previously supposed.

Fragmentation

Much of the biogenic material in the study area is fragmental. Bivalve fragments are the most abundant coarse grain type. Relative frequency of bivalve fragments in the thanatocoenosis has been shown previously in this report to vary consistently with grain size of the associated terrigenous sediment. High percentages of fragments occur in coarse sands while lower percentages are found in fine sands regardless

of water depth. Fragmentation of bivalve shells does not appear to be a function of physical energy available at the sea floor since trends of seaward increasing fragmentation on both lines L1 and L2 oppose the energy gradient.

Medium and coarse-grained sands of the offshore sand plain have been shown previously to be in oscillatory motion roughly 4 percent of the time (Figure 35), considering the summer offshore wave regime as typical. However, fine sands north of the outcrop area are resistant to movement because of their cohesive nature and high polychaete worm tube densities. The medium and coarse-grained sands possibly act as an abrasive mill for mechanical fragmentation and destruction of bivalves and other biogenic grain types. Fine sands north of the outcrop form a protective matrix for accumulations of unfragmented or only superficially broken bivalves.

The relationship between grain size and mechanical breakdown of bivalve shell material was investigated by Force (1969) who concluded that the impact of medium sized quartz grains in a turbulent environment was sufficient to erode and fragment bivalve shells. Tumbling barrel experiments confirmed the positive correlation between grain size and rate of fragmentation. Schafer (1972) emphasized the ability of agitated coarse sand to facet and fragment molluscan shells. Driscoll (1967) found that grain size is the most important factor in determining the degree of abrasion of bivalve shells in the shallow marine environment.

In addition to mechanical effects of coarser grain size on the rate of fragmentation, low rates of terrigenous sedimentation or actual erosion of the offshore sand plain (see discussion p. 82) exposes shell material to constant reworking by predators, scavengers, and burrowers.

The effect of predation is difficult to distinguish from physical fragmentation. Holes drilled by the Naticidae are found on the umbos of many bivalve shells of all sizes. Presumably these perforations reduce the strength of the shells but their importance with regard to fragmentation is unknown. Many types of ray inhabit the area which feed on mollusks and no doubt account for some fragmentation. The larger crabs may crush the shells of their victims. Sediment feeding burrowers such as *Plagiobrissus grandis* and the holothurians comminute shell material as it passes through their digestive system. However, this process must be only important for finer biogenic debris. Most biological fragmentation is probably the result of inadvertent breakage of shells by vagile endobenthic or epibenthic organisms during various forms of locomotory activity.

The abrupt decrease in relative frequency of bivalve fragments on the shoreface may be closely related to the diminutive size of the abundant species there. Small fragments produced from the shells of these species are not retained in the sampling screen and are therefore under-represented in the samples.

Surface Condition

The surface condition of biogenic debris in the study area varies from fresh to severely corraded (see Plate 7). Deterioration of coarse biogenic material is related to the combined effects of mechanical abrasion, endolithic microboring, and dissolution.

Surfaces of severely corraded bivalve shells are not polished as is common in beach accumulations. Rather, the shell surface assumes a pitted, chalky appearance. Endolithic boring algae and fungae, reported

by Perkins and Halsey (1971) to be active in nearshore marine waters, selectively attack molluscan shells and probably account for much of the surface deterioration. Slightly corraded shells often reveal a reticulated pattern of microborings when the surface is viewed at high power.

Dissolution of shell material seems to be of some importance. Unbroken tests of *Encope* spp., sometimes recovered from sediments of the offshore sand plain, show the effects of solution in the removal of the outer test wall and exposure of the system of interior canals (see Plate 7). Warme (1972) noted the commonly observed dissolution of shells in organic-rich lagoonal sediments. It appears that low pH may also develop in open marine sands where sufficient organic material accumulates. The decay of dispersed organic material and organics found in mud lenses beneath surficial sands on the offshore sand plain may form a source of interstitial carbonic acid.

An unknown period of time is required for molluscan shells to become severely corraded. Experiments performed by Driscoll (1967, 1970) on the Massachusetts coast showed that bivalve shells become slightly to moderately corraded after 2 to 3 years of exposure in a low energy sublittoral environment. Fresh or only slightly corraded molluscan shells are therefore probably indicative of recent mortality particularly in areas of nondeposition and bottom disturbance.

Relative frequency distributions of bivalve shells in four preservation categories are summarized in Figure 58 for locations on lines L1, L2, and RL1. Well preserved shells (fresh and slightly corraded) increase in relative frequency sharply on the lower shoreface at locations L19 and L29. On the offshore sand plain well preserved shells decline steadily in relative abundance with distance from the coast on line L2, but on

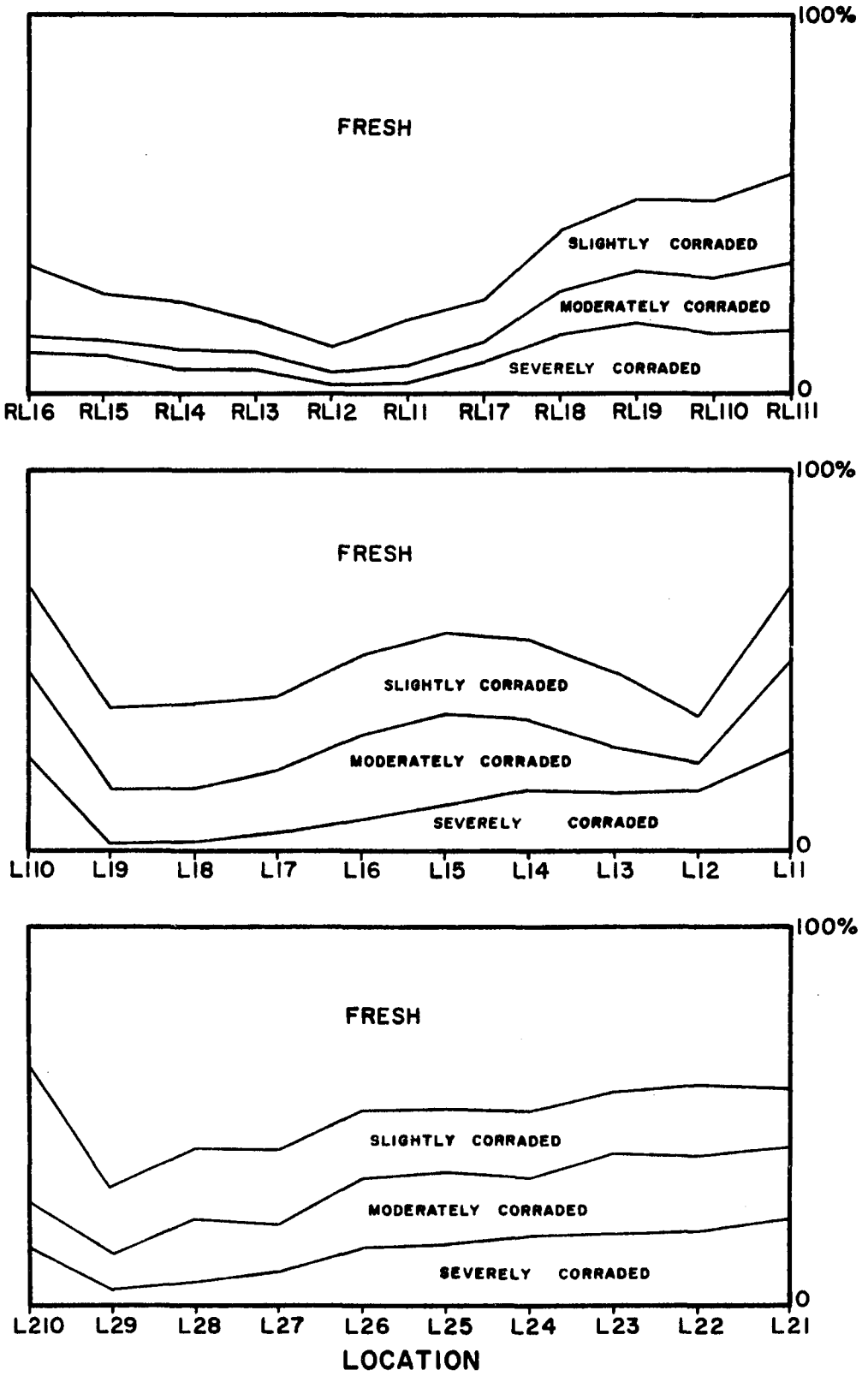


Figure 58. Mean Numerical Percentage of Fresh, Slightly Corraded, Moderately Corraded, and Severely Corraded Bivalve Shells.

line L1 their relative frequency at first decreases in a seaward direction and then reaches a maximum at location L12. South of the limestone outcrop on lines L1 and RL1 well preserved shells decline abruptly in proportion to an increase in occurrence of poorly preserved bivalves (moderately and severely corraded).

Correlation analysis of percent well preserved bivalve shells in the thanatocoenosis indicate a highly significant positive linear correlation (r=.78**) with terrigenous sediment grain size (ϕ). High percentages of well preserved shells occur in fine grained sands whereas high percentages of poorly preserved shells are found in coarse-grained sediments. This observation reflects the relationship between fragmentation and shell surface condition since both are responses of shell material to similar processes.

Conditions of coarse grain size, nondeposition, and bottom disturbance which favor fragmentation are also conducive to surface deterioration. Shells weakened by algal and fungal boring and dissolution are more readily fragmented and abraded when bottom sediments are in motion. Small fragments of degraded surface layers are removed by impact with larger quartz grains, and shells eventually fragment and are comminuted in a sequence similar to that described by Force (1969). In the absence of significant clastic sedimentation shell material remains exposed at the surface to continual abrasion. Reduced percentages of poorly preserved shells in fine sands north of the outcrop, accompanied by reduced fragmentation, is related to substrate stability and slightly increased rates of sedimentation of fine terrigenous sand derived from the quartzose limestone. Trends of seaward increasing percentages of poorly preserved and fragmental bivalves on the offshore sand plain reflects gradients of

of increasing grain size and decreasing clastic sedimentation in a seaward direction.

Selective Preservation

Of the skeletal remains found in marine sediments, mollusk shells are among the most resistant to abrasion and fragmentation by virtue of their dense microstructure. Echinoid tests are far less resistant to destruction not only because of their tendency to break along plate sutures but also because of the spongy microstructure of the plates. The strongest echinoid tests are those of the sand dollars, such as *Encope* spp., which are strengthened by internal pillars. In contrast, the adult tests of *Plagiobrissus grandis* are extremely fragile. Some implications of selective preservation have already been discussed with respect to echinoid populations.

The relative strength of molluscan shell material probably accounts for its abundance as shells and fragments in the thanatocoenosis of the study area. Within that group, experiments performed by Driscoll (1970) and Hallam (1967) have demonstrated that bivalve shells with high surface area to weight ratios (thin shells) are more readily fragmented and destroyed than thick shells even in low energy environments. Presumably, thick shelled species would experience even greater selection in open marine settings.

Relative frequency distributions of well preserved species and poorly preserved bivalve species are presented in Figures 59-64 for locations on lines L1, L2, and RL1. It is apparent that distributions presented earlier in this report (p. 151) for the thanatocoenosis in general are repeated in both preservation groups, with some notable

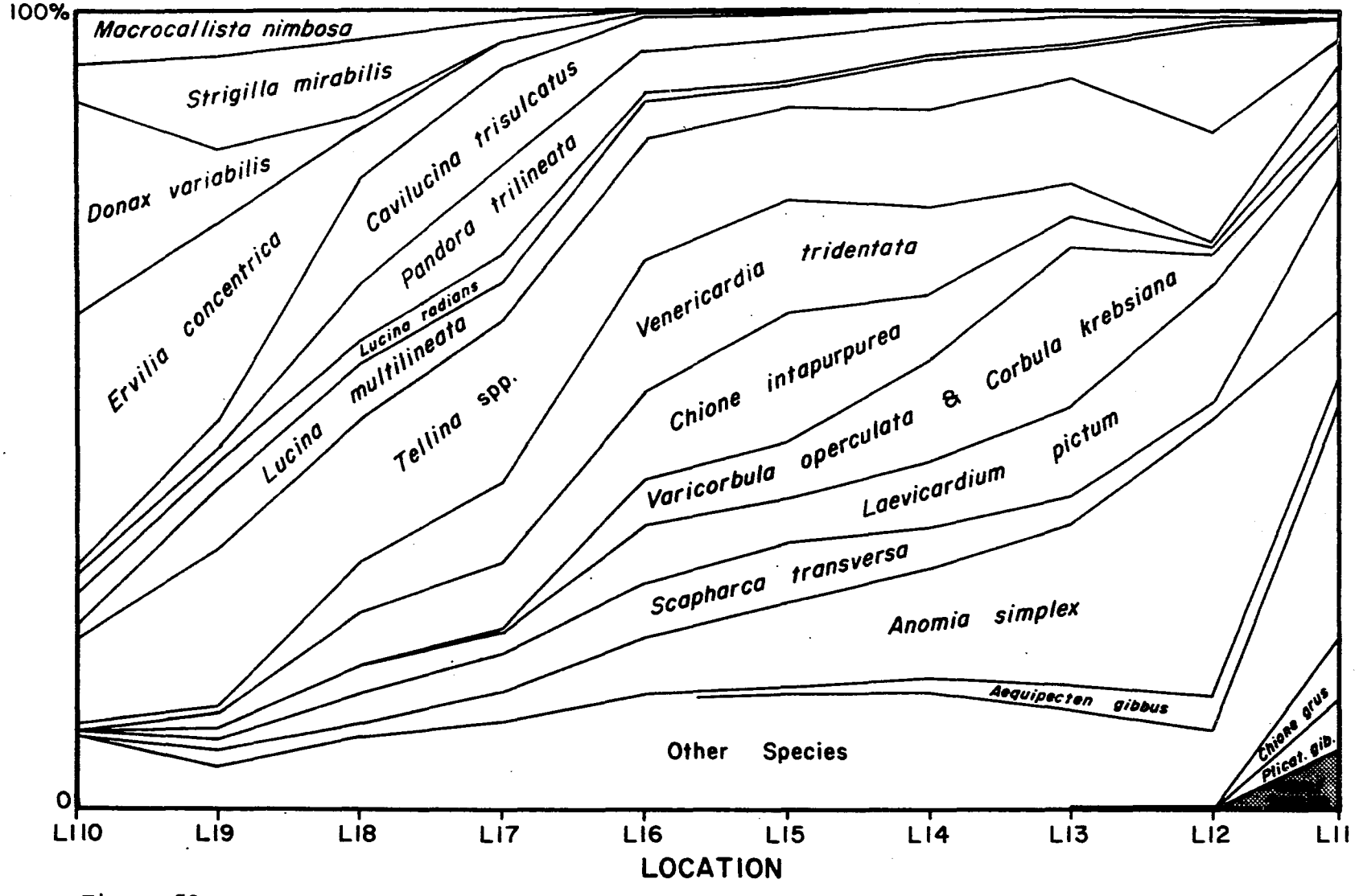


Figure 59. Mean Relative Frequency of Well Preserved Bivalve Species (>2.38mm.) - Line L1

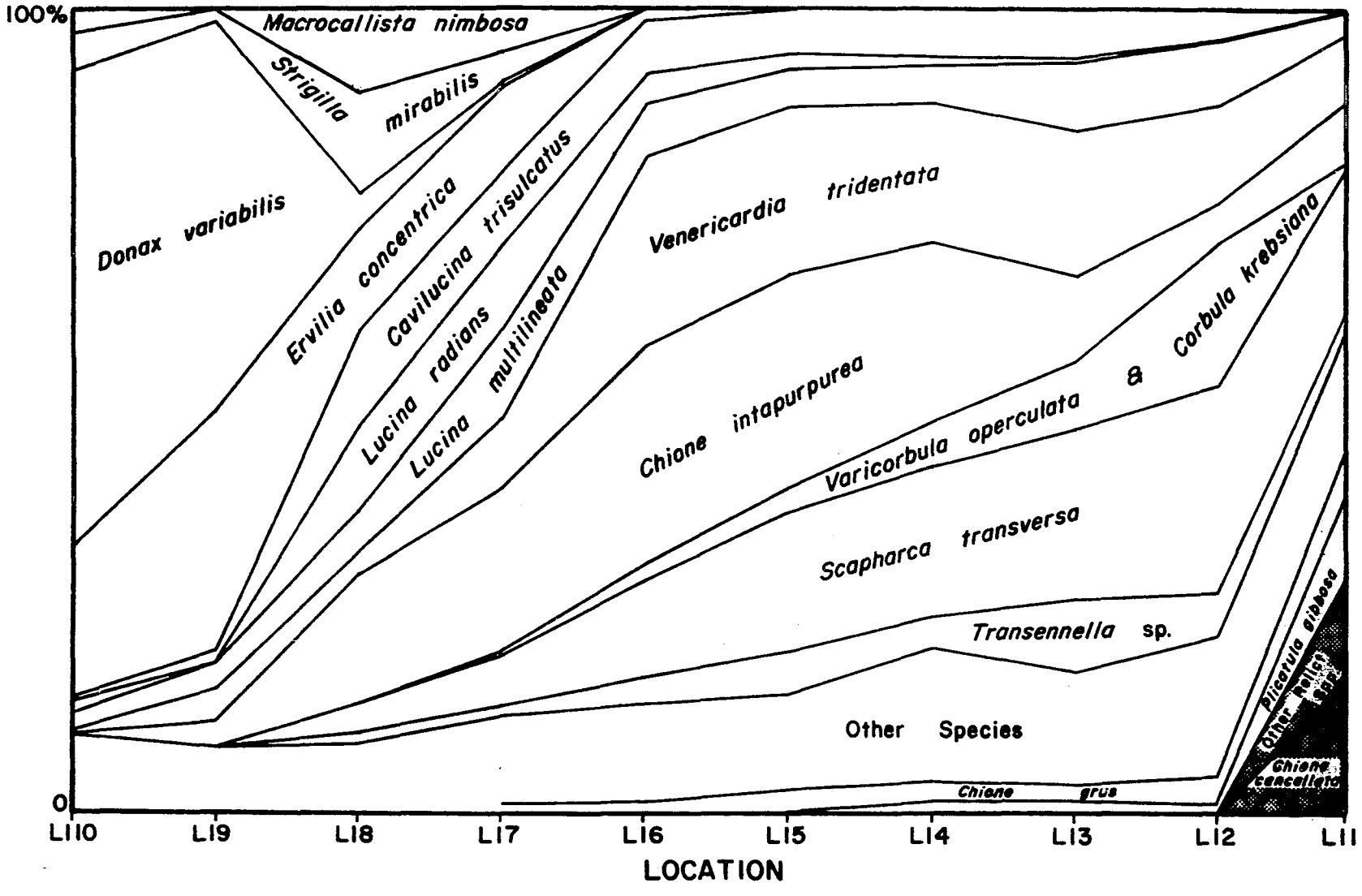


Figure 60. Mean Relative Frequency of Poorly Preserved Bivalve Species (>2.38mm.) - Line L1

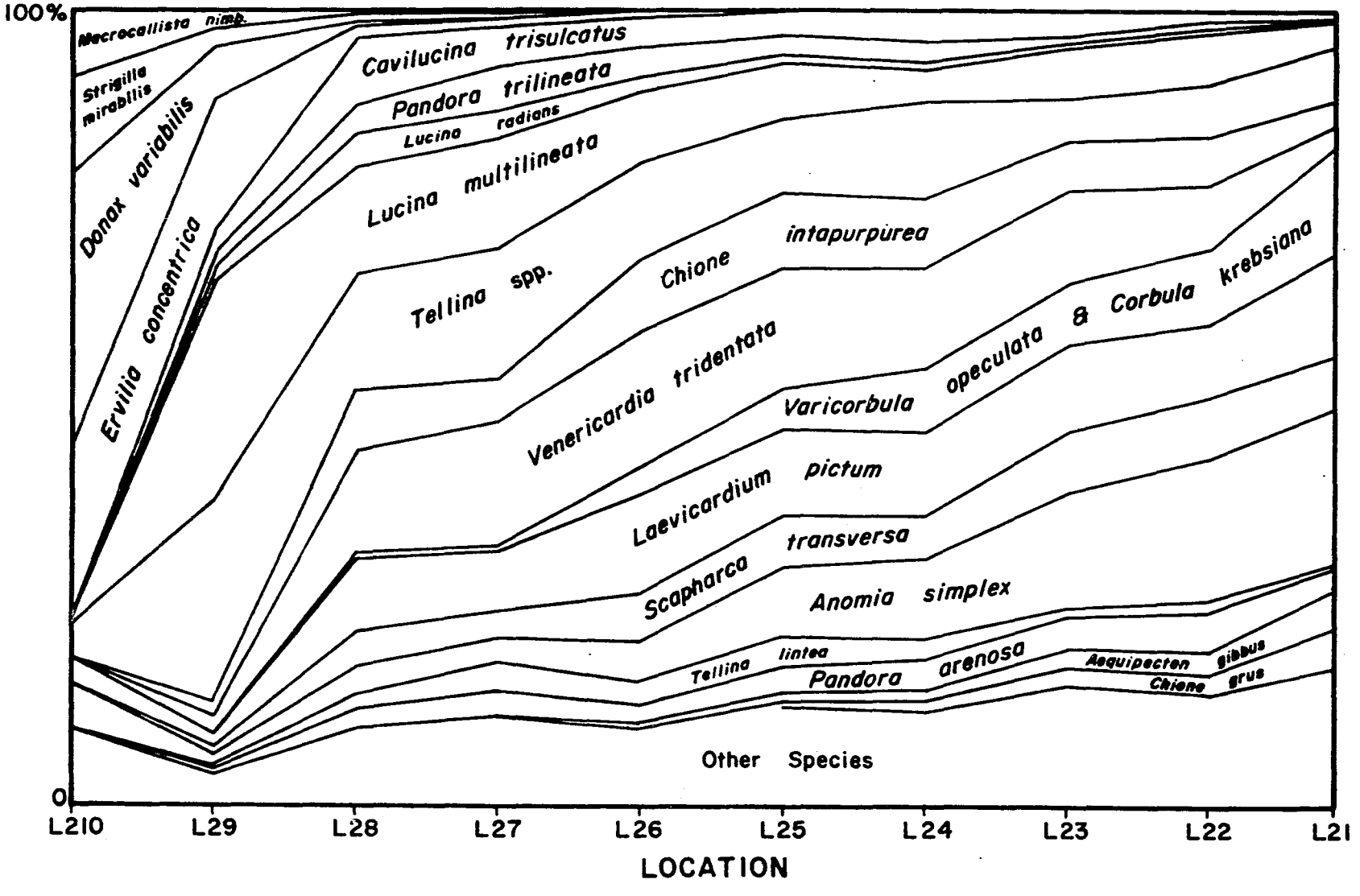


Figure 61. Mean Relative Frequency of Well Preserved Bivalve Species (>2.38mm.) - Line L2

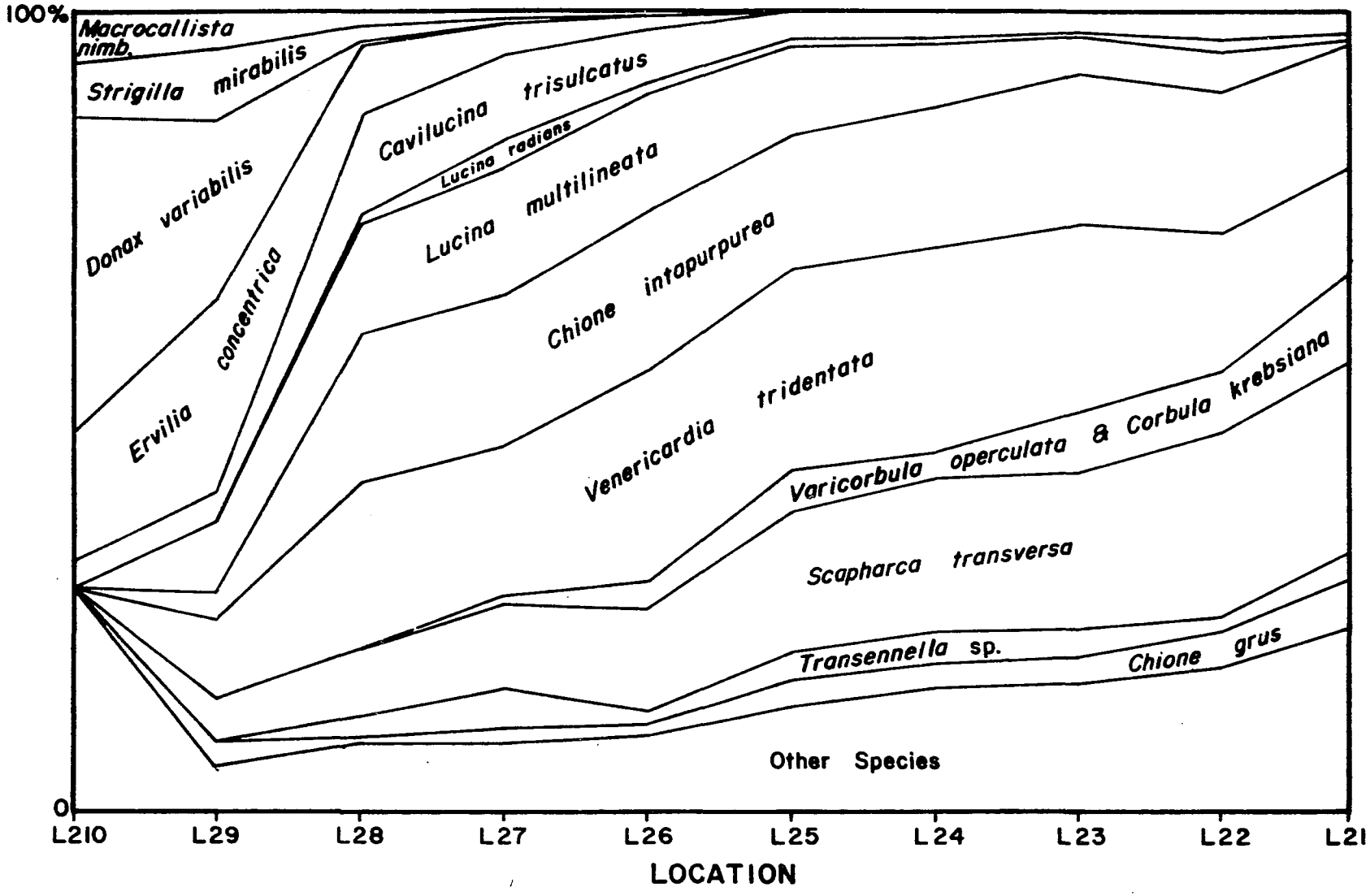


Figure 62. Mean Relative Frequency of Poorly Preserved Bivalve Species (>2.38mm.) - Line L2

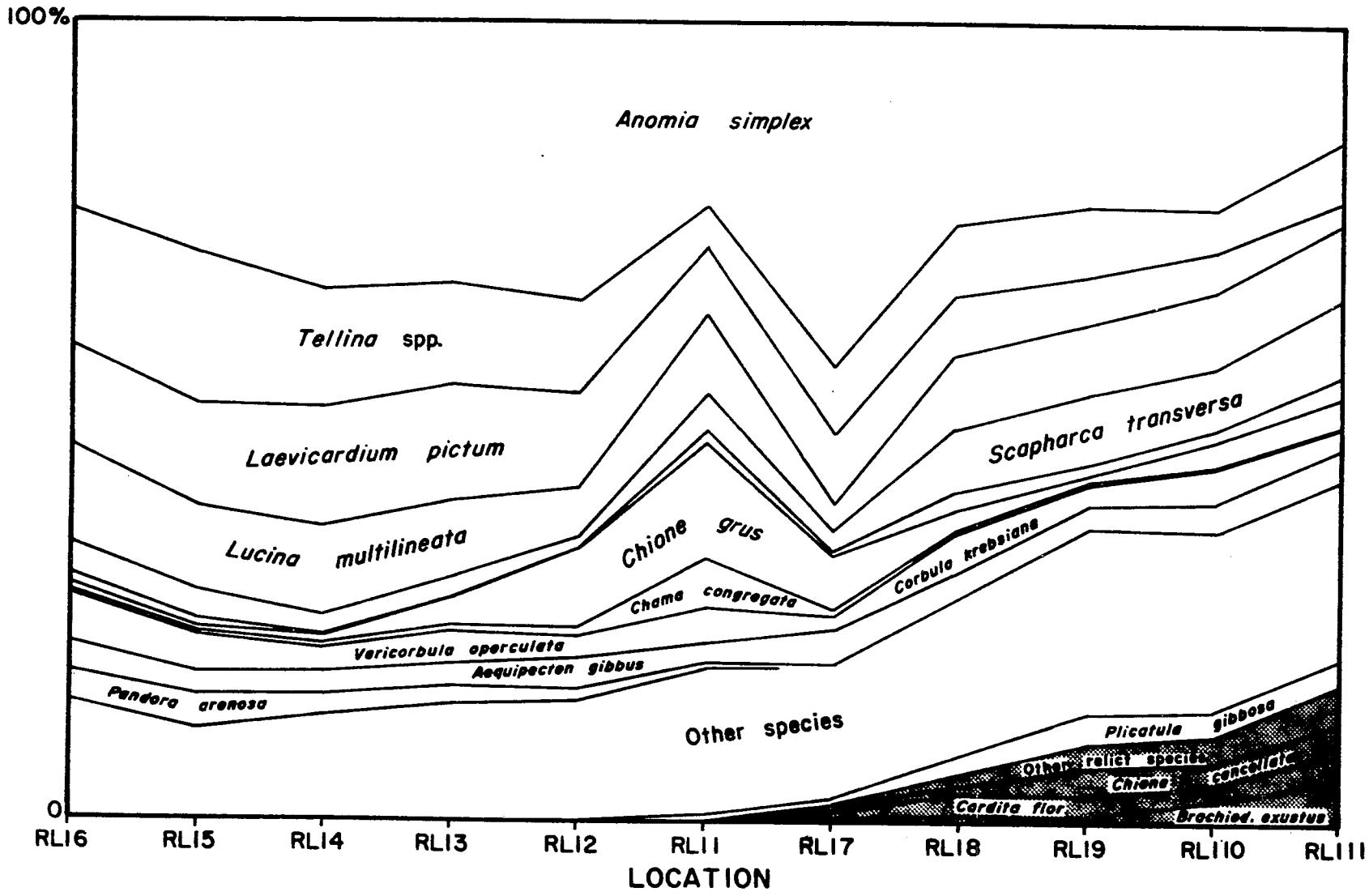


Figure 63. Mean Relative Frequency of Well Preserved Bivalve Species (>2.38mm.) - Line RL1

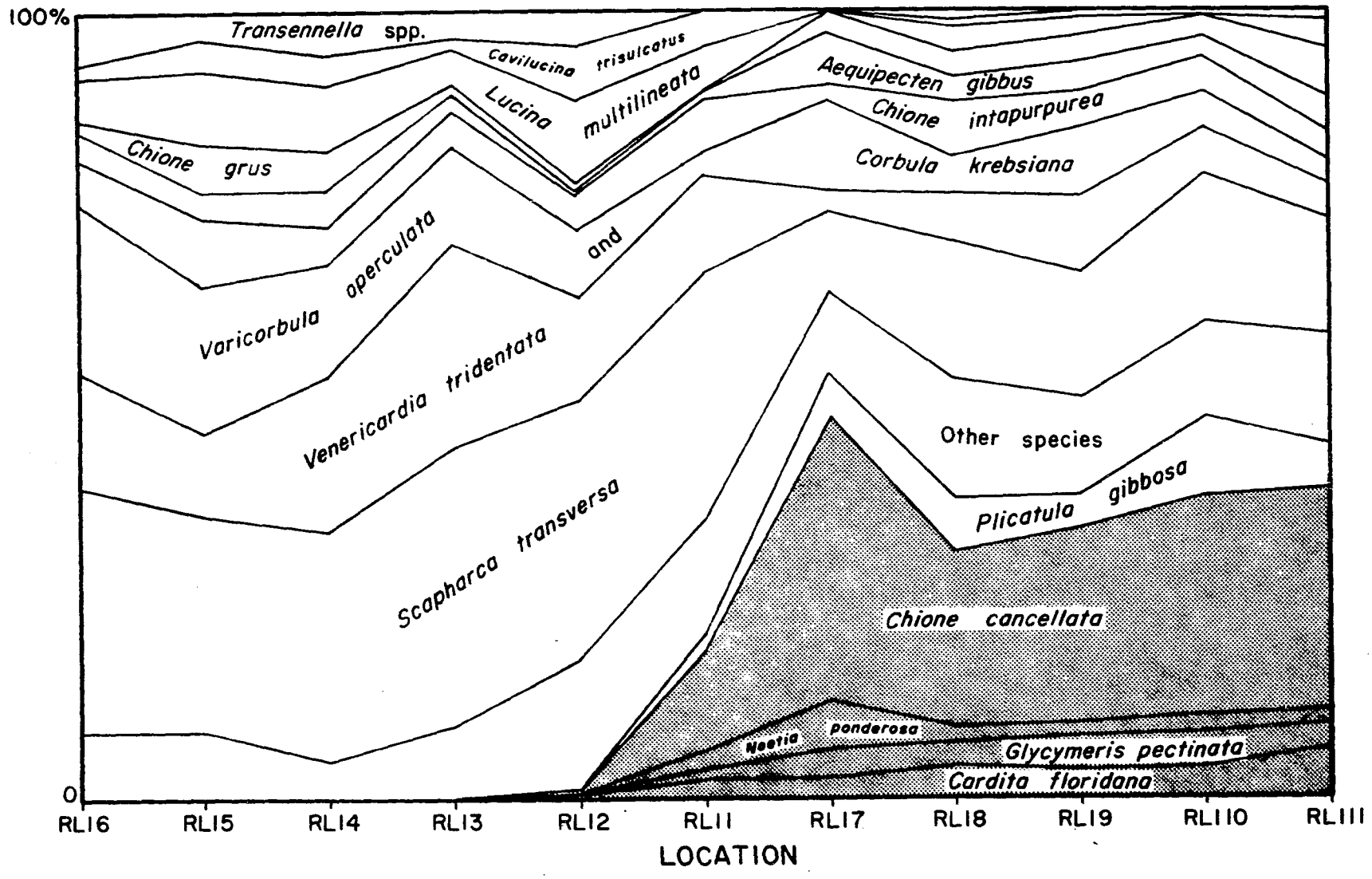


Figure 64. Mean Relative Frequency of Poorly Preserved Bivalve Species (>2.38mm.) - Line RL1

exceptions. Whereas *Laevicardium pictum*, *Anomia simplex*, and *Tellina* spp. are the most abundant well preserved species of the offshore sand plain bivalve assemblage, they are virtually absent as poorly preserved shells. In contrast, percentages of *Venericardia tridentata*, *Chione intapurpurea*, and *Scapharca transversa* are greatly expanded as poorly preserved shells. The former species are thin-shelled forms while the latter are robust in weight to surface area ratio.

Apparently, thin shells are rapidly destroyed in the study area by processes responsible for fragmentation and surface deterioration. Thin shells do not survive for sufficient lengths of time as whole shells to achieve poor preservation or to be identified in accumulations of poorly preserved shells. Robust shells, regardless of size, are not readily destroyed even in an environment of active sediment movement. They therefore form the bulk of poorly preserved shells in the death assemblage.

The relative frequencies of well preserved species suggest that selective preservation of robust shells may be active with respect to sediment grain size. *Tellina* spp., *Laevicardium pictum*, and, in particular, *Anomia simplex* shells are found in increased abundance at location L12 and line RL1 locations north of the limestone outcrop. Elsewhere on the offshore sand plain their relative frequency is considerably lower. Collections of living bivalves do not suggest any increase in population size for these three species north of the outcrop. An abundant source of juvenile *Anomia simplex* shells is the large population of this species found on the outcrop. Small *A. simplex* shells may be transported northward to accumulate with fine quartz sand derived from the limestone. In any event, the abundance of thin-shelled species in the thanatocoenosis of the fine sediments north of the outcrop may reflect their preservation

in that substrate and selective destruction in coarser sands. More data on the living bivalve community are necessary to support this interpretation.

Size Distribution

Investigations by Craig and Hallam (1963) and others have suggested that a useful criterion of death assemblage modification or sorting by currents is the total aspect of shell size distribution. Detailed specific size frequency distributions are controlled by specific biology. An apparent reduction in the number of small shells of a particular species may merely reflect the normal relationship between growth and mortality. However, a general reduction in frequency of small shells of many species indicates more strongly some degree of post-morten assemblage modification. Figure 65 summarizes, by weight-percent, the size frequency distribution of biogenic material in semiquantitative samples.

No biogenic material coarser than 7.93mm is found at locations L19 and L29. Seaward of those locations the percentage of coarser material increases. The percentage of biogenic material coarser than 7.93mm varies considerably on the offshore sand plain but remains a significant proportion of the total except at locations on lines L1 and RL1 north of the outcrop. At those locations 2.38 to 7.93mm grains constitute 90 percent of biogenic material. South of the outcrop the relative frequency of biogenic material in coarse fractions (>7.93mm) increases sharply due to the relict molluscan assemblage found there.

The relict assemblage is clearly depleted in small shells of many species. Relict shells are rarely found with biogenic material finer than 2.38mm and are infrequent in the 2.38 to 7.93mm size fraction. The

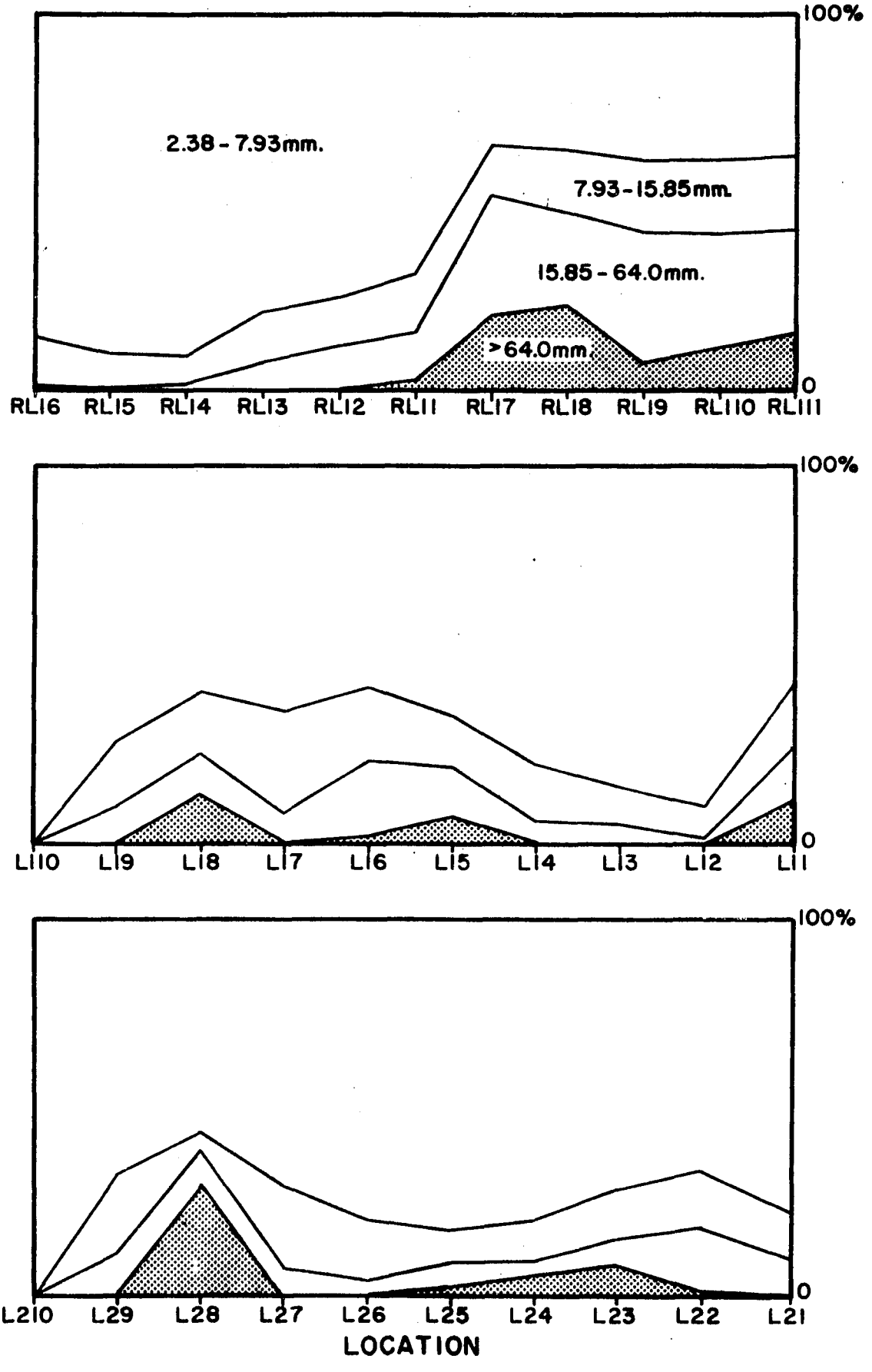


Figure 65. Mean Weight Percent of Biogenic Size Fractions

loss of small relict shells can be explained by sorting and transport of small shells or *in situ* destruction by processes of fragmentation and biochemical degration. Boucot (1953) noted that solution results in selective loss of small valves because of their large surface area to volume ratio. Other forms of *in situ* destruction, such as algal microboring, probably also reduce small shells more rapidly than large shells simply because they contain less calcium carbonate. The final result of current sorting or selective *in situ* destruction is identical; a coarse skewed size distribution alone is not an unqualified criterion of current winnowing.

Increased weight percent of biogenic material finer than 7.93mm in the fine sand north of the outcrop and its relative reduction elsewhere on the offshore sand plain is suggestive of selective destruction of finer biogenic material in medium and coarse sands. This suggestion is in agreement with observations of increased fragmentation and surface deterioration in those coarser sediments. However, the relationship between terrigenous sediment grain size and biogenic grain size for the lower shoreface and offshore sand plain in general is not statistically significant (r=.33). High relative abundances of small robust shells in poorly preserved bivalve assemblages suggest that selectivity, if it occurs, acts primarily through fragmentation of small thin shells. The possibility of selective destruction of bivalve shells has already been discussed.

High population densities or rates of production of small molluscan species in the fine sand biotope north of the outcrop may also explain increased relative frequencies of small biogenic grains in the thanatocoenosis there. This possibility is not supported by counts of living

mollusks. However, the data are not adequate to fully evaluate the living community.

The great abundance of small shells at all locations suggests that selective destruction is not an efficient mechanism of assemblage modification in the research area with respect to shell size in modern biogenic accumulations.

Disarticulation

The ratio of disarticulated to articulated bivalve shells has often been cited in the literature as a criterion of preburial modification of fossil assemblages (Fagerstrom, 1964; Boucot, 1953; Johnson, 1960). High proportions of disarticulated shells suggest some degree of transportation and bottom disturbance while the presence of many articulated shells indicates little alteration of the fossil community. However, the degree of disarticulation is also a function of ligament and hingement strength (Johnson, 1960; Fagerstrom, 1964). Trewin and Welsh (1972) found that *Ensis* shells remained articulated even after severe breakage of the valves while nearly all specimens of *Mactra* were disarticulated under the same conditions. In spite of such complications, disarticulation ratios have been used with success in the interpretation of fossil assemblages (Boucot et al., 1958; Johnson, 1962, 1965).

In contrast to the great numbers of disarticulated valves collected in semiquantitative samples in the study area, few shells were found in an articulated condition; these are tabulated by species and location in Table 10. Forty-nine species were recovered as articulated shells. Of these, 15 species were not found alive in the research area. Six

LOCATIONS

	L110	L19	L18	L17	L16	L15	L14	L13	L12	L11	L210	L29	L28	L27	L26	L25	L24	L23	L22	L21	RL16	RL15	RL14	RL13	RL12	RL11	RL17	RL18	RL19	RL110	RL111
Ervilia concentrica	5	8			1						4	6			1																
Macrocalista nimbosa		1																													
Donax variabilis			1							1																					
Strigilla mirabilis			1	1																											
Lucina radians		2		3				1					2	1	1																
Cavilucina trisulcatus			1	1	4	1		1		2		1	4	1	5	2	2	1													
Lucina multilineata				2					9			2						1			2	2	3	4		1	1	6	1	1	
Transennella cubaniana				1														2													1
Tellina spp.		1			2	8	11	14	3			7	1	1	4	3	5	2		5		1	2	1	2			1		1	
Venericardia tridentata			1	1	1	4	7	5	2	7				1	13	2	6	4	6	1	1	1	2	1		2		1		4	
Pandora trilineata				4	4	13	10	2					1	2	2	2		1													
Scapharca transversa				3	8	9	6	9	2				2	2	4	4	11	5	3	4	1	3	1			1		2	3		1
Lyonsia floridana				1																											
Laevicardium pictum				1			1	10	1	1			7	1	5	5	10	12	3	3			1	4	1	1			2	1	1
Crassinella lunulata					1	3	4	7		4			1		2	4	3	4	2	2	3		1	1					1	1	2
Chione intapurpurea					4	3	2	3						1	2	6	8	4	1	1			4	2					1	1	
Varicorbula operculata					11	17	31	142	12						2	3	2	4	1	1	13	9	9	4	3	1			1		1
Tellina lintea					1		4	2						2	1	2	5	1	3		1			1							
Plicatula gibbosa					1		2	1							1	1	1			1									2	1	2
Tellina interrupta					1										1		1	1													
Pandora arenosa					1	1	1																								
Ensis minor						1																									
Chione grus						1	1			2								1		1						1				4	5
Dinocardium robustum						1																									
Diplodonta punctata						1	1			1												1				2		1	2		
Corbula swiftiana						1			3	12							2	1	1			1		1	2	1		3	2	4	3
Verticordia ornata						1		2					1								1	2									
Corbula krebsiana								1	5	2										1		4	1	3		1	1	3	2		
Corbula barrattiana									1	6													1	1		12	2	1			1
Tellina alternata									1												1				1						
Lucina nassula									2													2	1		1						
Corbula dietziana										4												1				2	1	3	3	1	
Anodonta alba (juv.)																			1		3	4	4	3	1					2	1
Nuculana acuta																	1			1	1	1	1			4	1	5	1	1	3
Gouldia cerina														1		1		2		2			1	1	1	1		2	1		
Nucula proxima																							1	1		1	2				
Diplodonta nucleiformis															1		1			2			1								
Corbula contracta																									2	3					
Arcopsis adamsi																									1						
Lucina amiantus																										1					
Barbatia domingensis																										1					
Semele bellastriata																										1					
Mostia ponderosa																													1		1
Chione cancellata																													2		
Mactra fragilis																															2
Aequipecten gibbus																														2	
Cooperella atlantica													1																		
Macoma tenta														1																	
Macrocallista maculata														2				2													

Number of Articulated Shells of Bivalve Species
Locations on Lines L1, L2, and RL1

Table 10

articulated shells of the relict species *Noetia ponderosa, Chione cancellata,* and *Mactra fragilis* were collected from subsurface muds south of the outcrop on line RL1; the ligaments of these shells had completely deteriorated. Only *Venericardia tridentata, Crassinella lunulata,* and *Corbula* spp., as members of the modern bivalve community, were found as severely corraded articulated shells. All other articulated specimens were fresh in appearance with ligament intact.

The most abundant and consistently occurring articulated species are among those which are also most abundant in the living community and as disarticulated shells: *Cavilucina trisulcatus*, Tellina* spp.*, *Venericardia tridentata*, Pandora trilineata, Scapharca transversa, Laevicardium pictum*, Crassinella lunulata*, Chione intapurpurea,* and *Varicorbula operculata.* Those indicated with asterisks above are consistent in occurrence both as articulated shells and in collections of living bivalves. Comparisons of living and articulated shell distributions were made for each of these species with the Fisher Exact Probability Test. In all cases, except *Cavilucina trisulcatus,* the distribution of living versus articulated shells was found to be independent on a location by location basis. There was no significant relationship between the occurrence of articulated shells and living individuals for these species. This is interpreted as further indication of the random within-habitat occurrence of living bivalves and the inadequacy of semi-quantitative sample size.

When the distribution of articulated shells is viewed in terms of bathymetry it is apparent that their distribution is closely correlated with the living community and with disarticulated shells. In no instance were articulated shells found which indicated transport except for one

articulated *Donax variabilis* found on the lower shoreface (location L18).

The fresh character of the articulated specimens implies rapid disarticulation such that few articulated shells, regardless of hingement strength, survive intact to become corraded. Significantly, those articulated shells that do survive are of strongly articulated species. The numbers of articulated shells found in the fine sand north of the outcrop, where sediment movement is minimal, is not greater than in medium or coarse sand where frequent disturbance is the case. This observation suggests that disarticulation through biologic activity may be more important than physical sediment reworking.

Ratio of Opposite Valves

It is generally hypothesized that, for death assemblages which have undergone little preburial disturbance, the number of right valves and left valves should be approximately equal for any species and for the assemblage as a whole (Boucot, 1953; Johnson, 1960; Fagerstrom, 1964). Observations by Martin-Kaye (1951) and Behrens and Watson (1969) indicate that when accumulations of bivalve shells are transported, right and left valves are segregated as a result of mirror-image asymmetry. Other factors which may influence valve ratios are selective destruction due to structural valve differences, selective accumulation of unattached valves, selective predation, and selective transport due to size differences.

Anomia simplex and *Chama congregata* shells are found in extremely biased valve ratios. *Anomia simplex* is attached to large shells and rocks by a calcified byssus which perforates the right valve and cements

it to the substrate. Only left valves of *A. simplex* are found in the sediment. *Chama congregata* is cemented to shells and rocks by the left valve. Right valves of this species are therefore more common in shell accumulations.

All other bivalve species in the study area were expected to yield equal numbers of right and left valves if other selective processes are not operative. Counts of left and right valves were made for the most common species in samples on line L1 to test the hypothesis that numbers of opposite valves were equal. Species tested were: *Scapharca transversa, Venericardia tridentata, Laevicardium pictum,* and *Chione intapurpurea.* For all species tested the proportion of left and right valves was constant for all samples. In addition, the ratio of opposite valves did not differ significantly from 1:1 for *Venericardia tridentata, Laevicardium pictum,* and *Chione intapurpurea.* However, *Scapharca transversa* is characterized by a systematic reduction in the number of right valves in all samples. The left valve of this species is slightly larger than the right. Perhaps a mechanism such as selective destruction of the smaller right valve may account for their reduction in frequency.

The total number of right versus left valves for all semiquantitative samples, without regard to species, was tested for significant differences. *Anomia simplex* and *Chama congregata* were excluded from the analysis because of bias discussed above. The proportions of right and left valves were found to be the same for all samples on lines L1 and L2. Samples on line RL1 were found to have significant differences with regard to the proportion of opposite valves. Samples north of the outcrop had, in general, higher numbers of right valves while samples south of the outcrop had higher numbers of left valves. The explanation for this

observation is unknown. When averaged over samples on lines L1, L2, and RL1 the ratio of opposite valves did not differ significantly from 1:1. We may conclude both on the basis of individual species and the assemblage as a whole that segregation of opposite valves is not an active process in the study area.

Discussion

The thanatocoenosis may differ from the living community from which it was derived in three fundamental ways: 1) in composition, by the addition of exotic species or the removal of indigenous shells, 2) in density, by dispersal or concentration of biogenic material, or 3) in physical aspect, by fragmentation, disorientation, and other forms of alteration. The extent to which any or all of these assemblage modifications occur is a complex function of 1) rates of biotic production, 2) rates of sedimentation, and 3) frequency and magnitude of bottom disturbance. The thanatocoenosis of the offshore sand plain and shoreface can be discussed in terms of these variables.

Composition

Offshore Sand Plain

The offshore sand plain has been shown previously in this report to be an area of net shoreward sediment transport. Oscillatory and residual currents generated at the sea floor during infrequent storms are of sufficient velocity to entrain even very coarse shell material. Considerable landward transport of biogenic material was predicted from

these hydrodynamic considerations. However, the composition of the thanatocoenosis of the offshore sand plain appears to accurately reflect the composition of the living community. Although transportation of shell debris is occurring, as demonstrated near the outcrop, it has not altered the composition of the death assemblage to an appreciable extent. The only areas in which the death assemblage fails to reflect the living community are those areas where Early Holocene bay-inlet shells are found -- clearly not the result of transportation. The probable explanation for the absence of significant or detectable dispersive effects of transport on the composition of the death assemblage lies in the nature of the transportive process.

Wave-induced currents at the sea floor are largely oscillatory in nature on the offshore sand plain. Current residuals produce little net transport of biogenic material relative to time in oscillatory motion. In addition, large shells tend to be buried by peripheral scouring and thus are further detained. Low rates of sedimentation, non-deposition, or erosion on the offshore sand plain expose accumulated shell material to prolonged physical and biological reworking. Buried shells are recycled to the surface while exposed shells are fragmented and otherwise modified. Under such conditions of oscillatory motion and prolonged exposure net landward transport of biogenic material is nullified by relatively rapid destruction.

Of more influence on the composition of the thanatocoenosis is the selective destruction of thin-shelled species as shown by greatly reduced percentages of thin shells of poorly preserved bivalves. Such a process, if carried to completion, would seriously hinder the proper reconstruction of the molluscan community.

The dispersal of limestone-derived biogenic material on both the north and south side of the outcrop indicates that transportation is not always landward. It is difficult to envision seaward residual currents since wave approach in this nearshore zone is always from the sea. Perhaps some form of biologic diffusion is at work whereby the random effects of biological activity cause slow movement of shells away from the outcrop onto the adjacent sand plain.

Shoreface

The shoreface is characterized by coastward increasing mass transport velocities and frequency of bottom disturbance. Bed load transport theory suggests that both seaward and shoreward transport of biogenic material can occur depending on conditions of wave energy. In addition, compensatory currents may transport shells and sediment from the coast into deeper water.

The composition of the shoreface thanatocoenosis is quite similar to that of the living community but is altered in relative frequency by the addition of many *Donax variabilis* shells. High percentages of *D. variabilis* in shoreface death assemblages reflect extremely high population densities of this species in the adjacent nearshore community. Schafer (1972) suggested that accumulation of dead shells is a limiting factor in the continuance of a community. In spite of high rates of production, dead shells of *D. variabilis* do not accumulate in the biotope to such an extent that they limit growth of new populations. Rather, shells are entrained in this high energy environment and moved through the breakers to be deposited on the beach berm or are carried longshore and offshore by swift compensatory currents. Rip currents developed

during storms are probably an effective mechanism for distributing *D. variabilis* shells across the shoreface. Other members of the nearshore community are much less abundant; their contribution to the shoreface thanatocoenosis is not significant.

Rapidly diminishing frequencies of *Donax variabilis* towards the base of the shoreface suggest that offshore movement of shell material diminishes rapidly with depth and distance from shore. The reduction in offshore transport probably reflects diminished competence of compensatory currents. The oscillatory nature of wave-associated currents renders them ineffective as agencies of net transport of biogenic material. However, landward transport of shoreface shells does occur during storms as indicated by shell accumulations on the beach. The correspondence of shoreface molluscan populations with occurrences of shells in the death assemblage suggests that landward transport of these shells is largely offset by rapid destruction in an oscillatory regime. Only where directed currents such as rip currents are able to rapidly transport and deposit abundant shell material is assemblage composition altered to a significant degree.

Population Density

Shell population density in the sediment has been stated by Fagerstrom (1964) to reflect the interaction of biotic production, mortality, and rates of sedimentation. Density, expressed as the number of shells per unit volume, increases steadily seaward in the research area in response to diminished rates of clastic sedimentation. At all locations the density of dead shells is far greater than the density of the sparse living community. Production of shell material is sufficient to exceed

the rate at which it is comminuted and destroyed. Concentrations of shell material are found in ripple troughs indicating at least local oscillatory transport. However, the general low density of coarse shells and fragments is consistent with gradual accumulation of indigenous skeletal debris.

Physical Aspect

In contrast to the composition of the thanatocoenosis, some physical aspects of the death assemblage suggest that processes involving transportation are active. High proportions of fragmental remains and disarticulated shells, noted for all locations in the study area, are characteristic of assemblages which have been modified by transportation according to Johnson (1960), Fagerstrom (1964), and Boucot (1953). On the other hand, equal numbers of right and left valves and fine skewed size frequency distributions are believed by these workers to be indicative of little transport. *In situ* processes of shell destruction in the research area account for the observed conflicting physical evidence.

Johnson (1960) noted that "the results of exposure and transportation cannot be sharply distinguished in real circumstances" and further that "indigenous assemblages can exhibit the entire range of exposure effects depending upon the forces in action and the period of time involved." According to Johnson, exposure effects include fragmentation, abrasion, disarticulation of hard parts, and degradation of shell surfaces by solution and boring. Experiments performed by Hallam (1967) and Chave (1964) indicate that juvenile shells of all species fragment more readily than adult shells. Therefore, in some cases size sorting may also be related to exposure. The result of prolonged exposure in an

oscillatory regime is an accumulation of biogenic material which is altered by processes which accompany sediment motion but which shows little effect of net transportation.

Shells are degraded, fragmented, and disarticulated during long periods of exposure by oscillatory wave-induced sediment motion during storms and by biological activity during periods of calm weather. The frequency of bottom disturbance determines the relative importance of physical versus biological reworking. In the research area, shells on the offshore sand plain are infrequently moved by waves; the chalky appearance of corraded shells attests to continual degradation of endolithic algae and fungae. High frequency of disturbance on the shoreface is reflected in the clean, abraded appearance of shells there.

Oscillatory motion and biological activity do not appear capable of altering, to a significant extent, the ratio of opposite valves or the general size frequency distribution of shell material either on the shoreface or offshore sand plain. The observed reduction in small shells in the relict assemblage may reflect prolonged exposure but may also be related to size sorting under previous higher energy conditions during the Holocene sea level rise.

Summary

Processes of oscillatory sediment movement and biological reworking account for the observed physical aspects of shell preservation and disarticulation. Net transportation of biogenic material, although it is occurring, is of minor importance with respect to assemblage composition on the offshore sand plain. On the shoreface, seaward transport of nearshore shells is significant. Landward transport of biogenic material by

oscillatory bed load transport processes is offset by rapid destruction of shells; local production of shell material is therefore the dominant influence on thanatocoenosis composition. Only where directed currents rapidly supply abundant shells is the death assemblage significantly altered in composition.

The thanatocoenosis is adequate to form a basis for the reconstruction of the living community composition with respect to those organisms that contribute skeletal material. However, a substantial portion of the living community is lost through non-preservation. Where relict bay-inlet shells occur in abundance they constitute an important source of confusion in the interpretation of the thanatocoenosis.

SUMMARY OF CONCLUSIONS

Sediments

1. The research area can be conveniently subdivided into the shoreface and the offshore sand plain on the basis of bathymetry.

2. Clastic sediments are distributed in textural zones which parallel the coast. Fine sands are found on the upper shoreface, medium sands on the lower shoreface and inner offshore sand plain, and coarse sands on the offshore sand plain.

3. Discrete grain size populations of terrigenous sand are recognized as genetic units: 1) fine upper shoreface sands supplied by the present longshore drift system, 2) medium lower shoreface sands possibly derived from strata of the shoreface, 3) coarse sands of the offshore sand plain representing reworked Pleistocene alluvial sediments, 4) fine sands derived from erosion of a submerged limestone outcrop and transported coastward to form an anomalous fine sand body on the offshore sand plain, 5) coarse quartz grains from the limestone.

4. The limestone outcrop appears to be an outlier of Pamlico-age, quartzose, biogenic, marine sand which was cemented subaerially during Wisconsin and Early Holocene time.

5. Sand size biogenic material and terrigenous quartz sand have been size sorted under similar hydrodynamic conditions giving rise to similar trends in modal grain size for both fractions despite considerable original size differences.

Dynamics of Sediment Transport

6. Sediment movement is active on the shoreface and offshore

sand plain. The dominant mechanisms of sediment transport are wave-generated bottom currents acting normal to the coast and compensatory currents on the upper shoreface.

7. Terrigenous sediment grain size is at least in partial adjustment to conditions of incident wave energy, depth, and bottom slope in the study area.

8. Bedload transport theory suggests that direction of transport is always landward on the offshore sand plain but may be landward or seaward on the shoreface depending on the relationship between effective grain size and mass transport velocity.

9. Sediment textures developed during lowered Pleistocene sea level are being reinforced and modified by the present hydrodynamic regime. The sediments are therefore palimpsest.

10. Orbital current velocities are frequently sufficient to move very coarse biogenic material everywhere in the research area. Bedload transport theory permits prediction of direction of transport and provides a framework for the investigation of the relationship between biota and biogenic accumulations.

Biota

11. The major groups of organisms of the level bottom invertebrate biota include: mollusks, echinoids, asteroids, coralline algae, polychaetes, crustaceans, and bryozoans. Of these, mollusks, echinoids, and coralline algae dominate the thanatocoenosis.

12. The limestone substrate supports a diverse epifaunal association and many boring or cryptic species. However, only mollusks and coral contribute significant coarse biogenic material to shell accumula-

tions in the outcrop area.

13. The biota is distributed in zones which parallel the coast. The level bottom biota can be subdivided into a nearshore *Tellina* parallel community and a shoreface and offshore sand plain *Venus* parallel community. The limestone biota is a distinct biocoenosis.

14. A variety of organisms intensely rework and modify the sediments: *Callianassa* spp. near the coast; *Balanoglossus* sp. on the shoreface; echinoids on the lower shoreface and offshore sand plain; polychaetes on the shoreface and in the fine sand body north of the outcrop; mollusks throughout the area.

Paleoecologic Considerations

15. The distribution and composition of fragmental biogenic material reflects adequately the distribution and composition of the living community with some effects of selective preservation.

16. The distribution of bivalves in the thanatocoenosis accurately reflects their distribution in the community with the exception of transported accumulations of *Donax variabilis* and relict molluscan shells.

17. Isolated areas of relict bay-inlet molluscan assemblages are found on the offshore sand plain which represent shallow water stages of the Holocene transgression. These shells are locally an important component of the death assemblage.

18. Accumulations of *Donax variabilis* indicate considerable downslope transport on the shoreface by compensatory currents. Net transport predicted by bedload transport theory has had little influence on the composition of the thanatocoenosis. Oscillatory bedload movement is

inefficient as an agency of net transport and leads to rapid destruction of shell material.

19. Low rates of sedimentation combined with infrequent bottom disturbance on the offshore sand plain favor biological degradation of shell material while higher rates of bottom disturbance favor abrasion on the shoreface.

20. Physical aspects of shell preservation, disarticulation, disassociation, and size frequency distribution can be attributed to prolonged exposure in an oscillatory regime.

21. The thanatocoenosis forms a basis for the accurate reconstruction of the community with respect to those organisms which contribute skeletal material. Spurious interpretation may result from the presence of relict faunal elements.

BIBLIOGRAPHY

Abbott, R. T., 1954, American Seashells, D. van Nostrand Co., Inc., New York, N. Y., 541 pp.

Adams, R. D., 1967, Program for hydrometer analysis, C. S. I. Bull., n. 1, p. 43-47.

Allee, W. C., 1934, Concerning the organization of marine coastal communities, Ecol. Mono., n. 4, p. 541-554.

Allen, G. P., 1971, Relationship between grainsize parameter distribution and current patterns in the Gironde Estuary, Jour. Sed. Pet., v. 41, p. 74-88.

Alt, D., and Brooks, H. K., 1965, Age of the Florida marine terraces, Jour. Geol., v. 68, p. 481-497.

Antoine, J. W., and Gilmore, J. C., 1970, Geology of the Gulf of Mexico, Texas A & M Univ. College of Geosci., contr. n. 457.

Ballard, R. D., and Uchupi, C., 1970, Morphology and Quaternary history of the continental shelf of the Gulf Coast of the United States, Bull. Mar. Sci., v. 20, p. 547-557.

Bathurst, R. G. C., 1971, Carbonate Sediments and Their Diagenesis, Elsevier, Amsterdam, 620 pp.

Behrens, W. E., and Watson, R. L., 1969, Differential sorting of pelecypod valves in the swash zone, Jour. Sed. Pet., v. 39, p. 159-165.

Bird, S. O., 1970, Shallow-marine and estuarine benthic molluscan communities from area of Beaufort, North Carolina, Am. Assoc. Petr. Geol. Bull., v. 54, p. 1651-1676.

Bloom, S. A., et al., 1972, Animal-sediment relations and community analysis of a Florida estuary, Mar. Biol., v. 13, p. 43-56.

Boillot, G., 1964, Organogenic gradients in the study of neritic deposits of biological origin: the example of the western English Channel, Mar. Geol., v. 3, p. 359-367.

Boucot, A. J., 1953, Life and death assemblages among fossils, Am. Jour. Sci., v. 251, p. 25-40.

Boucot, A. J., et al., 1958, Distribution of brachiopod and pelecypod shells by currents, Jour. Sed. Pet., v. 28, p. 321-332.

Bretsky, P. W., 1973, Why 'communities'? - comment, Geology, v. 1, p. 59.

Cadee, G. C., 1968, Molluscan biocoenoses and thanatocoenoses in the Ria de Arosa, Galacia, Spain, E. J. Brill, Leiden, 121 pp.

Chave, K. E., 1964, Skeletal durability and preservation, in Approaches to Paleoecology, Imbrie, J., and Newell, N. (eds.), J. Wiley and Sons, Inc., New York, N. Y., 432 pp.

Cherry, S. A., 1966, Sand movement along equilibrium beaches north of San Francisco, Jour. Sed. Pet., v. 36, p. 341-357.

Clifton, H. E., 1971, Orientation of empty pelecypod shells and shell fragments in quiet waters, Jour. Sed. Pet., v. 41, p. 671-682.

Clifton, H. E., et al., 1971, Depositional structures and processes in the non-barred high energy nearshore, Jour. Sed. Pet., v. 41, p. 651-670.

Cole, L. C., 1949, The measurement of interspecific association, Ecology, v. 30, p. 411-424.

Craig, G. Y., 1953, Fossil communities and assemblages, Am. Jour. Sci., v. 251, p. 547-548.

_____, 1967, Size-frequency distributions of living and dead populations of pelecypods from Biminy, Bahamas, B. W. I., Jour. Geol., v. 75, p. 34-45.

Craig, G. Y., and Hallam, A., 1963, Size-frequency and growth ring analysis of Mytilus edulis and Cardium edule and their paleoecological significance, Palaeontology, v. 6, p. 731-750.

Craig, G. Y., and Jones, N. S., 1966, Marine benthos and paleoecology, Palaeontology, v. 9, p. 30-38.

Craig, G. Y., and Oertel, G., 1966, Deterministic models of living and fossil populations of animals, Quart. Jour. Geol. Soc. London, v. 122, p. 315-355.

Creager, J. S., and Sternberg, R. W., 1972, Some specific problems in understanding bottom sediment distribution and dispersal on the continental shelf, in Shelf Sediment Transport, Swift, D. J. P., et al. (eds.), Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., 656 pp.

Curray, J. R., 1960, Sediments and history of the Holocene transgression, continental shelf, northwestern Gulf of Mexico, in Recent Sediments, Northwest Gulf of Mexico, Shepard, F. P., et al. (eds.), Am. Assoc. Petr. Geol. Pub., 394 pp.

Dragovich, A., and Kelley, J. A., 1964, Ecological observations of macroinvertebrates in Tampa Bay, Florida, Bull. Mar. Sci., v. 14, p. 74-102.

Driscoll, E. G., 1967, Experimental field study of shell abrasion, Jour. Sed. Pet., v. 37, p. 1117-1123.

Driscoll, E. G., 1970, Selective bivalve destruction in marine environments, a field study, Jour. Sed. Pet., v. 40, p. 898-905.

Duane, D. B., 1964, Significance of skewness in recent sediments, western Pamlico Sound, North Carolina, Jour. Sed. Pet., v. 34, p. 864-874.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, in Classification of Carbonate Rocks, Ham, W. E. (ed.), Am. Assoc. Petr. Geol., Tulsa, Okla., p. 108-121.

Emery, K. O., 1968a, Relict sediments on the continental shelves of the world, Am. Assoc. Petr. Geol. Bull., v. 52, p. 445-464.

_____, 1968b, Positions of empty pelecypod valves on the continental shelf, Jour. Sed. Pet., v. 38, p. 1264-1269.

Fager, E. W., 1957, Determination and analysis of recurrent groups, Ecology, v. 38, p. 586-595.

Fagerstrom, J. A., 1964, Fossil communities in paleoecology; their recognition and significance, Geol. Soc. Am. Bull., v. 75, p. 1197-1216.

Folk, R. L., 1959, Practical petrographic classification of limestones, Am. Assoc. Petr. Geol. Bull., v. 43, p. 1-38.

_____, 1968, Petrology of Sedimentary Rocks, Hemphill's, Austin, Texas, 170 pp.

Folk, R. L., and Robles, R., 1964, Carbonate sands of Isla Perez, Alacran Reef complex, Yucatan, Jour. Geol., v. 72, p. 255-292.

Force, L. M., 1969, Calcium carbonate size distribution on the West Florida shelf and experimental studies on the microarchitectural control of skeletal breakdown, Jour. Sed. Pet., v. 39, p. 902-934.

Foster, J. B., and Pascale, C. A., 1971, Selected water resource records for Okaloosa County and adjacent areas, Fla. State Geol. Surv. Inform. Circ., n. 67, 95 pp.

Frank, W. M., and Friedman, G. M., 1973, Continental shelf sediments off New Jersey, Jour. Sed. Pet., v. 43, p. 224-237.

Ginsberg, R. N., and Lowenstam, H. A., 1958, The influence of marine bottom communities on the depositional environment of sediments, Jour. Geol., v. 66, p. 310-318.

Goldsmith, V., 1966, Dramatic changes in the recent sedimentary environment of Choctawhatchee Bay, Florida (abst.), Geol. Soc. Am. Spec. Paper, n. 101, p. 359-360.

Gorsline, D. S., 1966, Dynamic characteristics of West Florida Gulf Coast beaches, Mar. Geol., v. 4, p. 187-206.

Hallam, A., 1967, Interpretation of size-frequency distribution in molluscan death assemblages, Palaeontology, v. 10, p. 25-42.

Hanor, J. S., and Marshall, N. F., 1971, Mixing of sediments by organisms, in Trace Fossils, Perkins, B. F. (ed.), Louisiana State Univ. Misc. Pub. 71-1, p. 127-135.

Hedgepeth, G. H., 1953, An introduction to the zoogeography of the northwestern Gulf of Mexico with reference to the invertebrate fauna, Texas Univ. Inst. Mar. Sci. Contr., v. 3, p. 111-211.

Hoskin, C. M., and Nelson, R. V., 1971, Size modes in biogenic carbonate sediment, southeastern Alaska, Jour. Sed. Pet., v. 41, p. 1026-1037.

Hjulstrom, F., 1935, Study of the morphological activity of rivers as illustrated by the River Fyris, Bull. Geol. Inst. Uppsala, v. 14.

Hyne, N. J., and Goodell, H. G., 1967, Origin of the sediments and submarine geomorphology of the inner continental shelf off Choctawhatchee Bay, Florida, Mar. Geol., v. 5, p. 299-313.

Inman, D. L., 1963, Ocean waves and associated currents, in Submarine Geology, Shepard, F. P. (ed.), Harper and Row, New York, N. Y., 557 pp.

Ippen, A. T., 1966, Estuarine and Coastline Hydrodynamics, McGraw-Hill, Inc., New York, N. Y., 744 pp.

Ippen, A. T., and Eagleson, P. S., 1955, A study of sediment sorting by waves shoaling on a plane beach, Beach Erosion Board Tech. Mem., n. 63, Washington, D. C.

Johnson, R. G., 1957, Experiments on the burial of shells, Jour. Geol., v. 65, p. 527-535.

_____, 1960, Models amd methods for analysis of the mode of formation of fossil assemblages, Geol. Soc. Am. Bull., v. 71, p. 1075-1086.

_____, 1962a, Mode of formation of marine fossil assemblages of the Pleistocene Millerton Formation of California, Geol. Soc. Am. Bull., v. 73, p. 113-130.

_____, 1962b, Interspecific associations in Pennsylvanian fossil assemblages, Jour. Geol., v. 70, p. 32-55.

Johnson, R. G., 1964, The community approach to paleoecology, in Approaches to Paleoecology, Imbrie, J., and Newell, N. (eds.), John Wiley and Sons, Inc., New York, N. Y., 432 pp.

_____, 1965, Pelecypod death assemblages of Tomales Bay, California, Jour. Paleo., v. 39, p. 80-85.

Keith, D. E., and Hulings, N. C., 1965, A quantitiative study of selected nearshore infauna between Sabine Pass and Bolivar Point, Texas, Texas Univ. Inst. Mar, Sci. Contr., v. 10, p. 33-40.

Kelling, G., and Williams, P. F., 1967, Flume studies and reorientation of shells, Jour. Geol., v. 75, p. 243-267.

Kier, P. M., and Grant, R. E., 1965, Echinoid distribution and habits, Key Largo Coral Reef Preserve, Florida, Smithsonian Misc. Pub., v. 149, n. 6, 68 pp.

Kofoed, J. W., and Gorsline, D. S., 1963, Sedimentary environments in Apalachicola Bay and vicinity, Florida, Jour. Sed. Pet., v. 33, p. 205-219.

Kurten, B., 1964, Population structure in paleoecology, in Approaches to Paleoecology, Imbrie, J., and Newell, N. (eds.), John Wiley and Sons, Inc., New York, N. Y., 432 pp.

Kwon, H. J., 1969, Barrier islands of the northern Gulf of Mexico coast: sediment source and development, Louisiana State Univ. Coastal Studies Inst. Tech. Rept., n. 75, 51 pp.

Ladd, H. S., 1951, Brachish-water and marine assemblages of the Texas coast with special reference to mollusks, Texas Univ. Inst. Mar Sci. Contr., v. 1, p. 125-164.

Ladd, H. S., et al., 1957, Environments and facies of existing bays on the central Texas coast, in Treatise on Marine Ecology and Paleoecology, v. 2, Ladd, H. S. (ed.), Geol. Soc. Am. Mem., n. 67, 1077 pp.

Lawrence, D. L., 1968, Taphonomy and information loss in fossil communities, Geol. Soc. Am. Bull., v. 79, p. 1315-1330.

Lever, J., 1966, Modes of sorting of shell valves on a sandy beach studied with artificial valves of Donax vittatus, Malacologia, v. 5, p. 85.

Lowman, S. W., 1951, The relationship of the biotic and lithic facies in Recent Gulf Coast sedimentation, Jour. Sed. Pet., v. 21, p. 233-237.

Ludwick, J. C., 1964, Sediments of the northeastern Gulf of Mexico, in Papers in Marine Geology, Miller, R. L. (ed.), MacMillan Co., New York, N. Y., 531 pp.

Ludwick, J. C., and Walton, W. R., 1957, Shelf-edge calcareous prominences in northeastern Gulf of Mexico, Am. Assoc. Petr. Geol. Bull., v. 41, p. 2054-2101.

Lynch, S. A., 1954, Geology of the Gulf of Mexico, in Gulf of Mexico, its Origins, Waters, and Marine Life, U. S. Fisheries and Wildlife Serv. Bull., n. 89, p. 67-86.

Lyons, W. G., et al., 1971, Preliminary inventory of marine invertebrates collected near the electrical generating plant, Crystal River, Florida, in 1969, Florida Dept. Nat. Resources, Mar. Res. Lab. Prof. Paper, n. 14, 45 pp.

MacFadyen, A., 1963, Animal Ecology, Aims and Methods, Pitman, London, 344 pp.

MacGinitie, G. E., 1939, Littoral marine communities, Am. Midland Nat., v. 21, p. 28-55.

MacNeil, F. S., 1950, Pleistocene shorelines in Florida and Georgia, U. S. Geol. Surv. Prof. Paper 221-F, p. 95-107.

Marsh, O. T., 1966, Geology of Escambia and Santa Rosa Counties, western Florida panhandle, Florida State Geol. Surv. Bull., n. 46.

Martin-Kaye, 1951, Sorting of lamellibranch valves on beaches in Trinidad, B. W. I., Geol. Mag., v. 88, p. 432-435.

McAlester, A. L., et al., 1964, Ecology of Pleistocene mollusks from Martha's Vineyard - a reconsideration, Jour. Paleo., v. 38, p. 985-991.

McCave, I. N., 1971, Wave effectiveness at the sea bed and its relationship to bed forms and deposition of mud, Jour. Sed. Pet., v. 41, p. 89-96.

McClennen, C. E., 1973, New Jersey continental shelf near bottom current meter records and recent sediment activity, Jour. Sed. Pet., v. 43, p. 371-380.

McNulty, J. K., et al., 1962, Level bottom communities from Biscayne Bay and neighboring areas, Bull. Mar. Sci., v. 12, p. 204-233.

Menard, H., and Boucot, A. J., 1951, Experiments on the movement of shells by water, Am. Jour. Sci., v. 249, p. 131-151.

Milliman, J. D., and Emery, K. O., 1968, Sea levels during the past 35,000 years, Science, v. 162, p. 1121-1123.

Mobius, K., 1877, Die Auster und die Austerwirtschaft, Berlin.

Nagle, J. S., 1967, Wave and current orientation of shells, Jour. Sed. Pet., v. 37, p. 1124-1138.

Nasu, N., 1964, The provenence of the coarse sediments on the continental shelves and trench slopes off the Japanese Pacific coast, in Marine Geology, Miller, R. L. (ed.), MacMillan Co., New York, N. Y., 531 pp.

Olson, E. C., 1957, Size-frequency distributions in samples of extinct organisms, Jour. Geol., v. 65, p. 309-333.

Palacas, J. G., et al., 1968, Organic geochemistry of Recent sediments in the Choctawhatchee Bay area, Florida - a preliminary report, U. S. Geol. Surv. Prof. Paper 600-C, p. 97-106.

Parker, R. H., 1956, Macro-invertebrate assemblages as indicators of sedimentary environments in east Mississippi Delta region, Am. Assoc. Petr. Geol. Bull., v. 40, p. 295-376.

_____, 1959, Macro-invertebrate assemblages of Central Texas coastal bays and Laguna Madre, Am. Assoc. Petr. Geol. Bull., v. 43, p. 2100-2166.

_____, 1960, Ecology and distribution patterns of macro-invertebrates, northern Gulf of Mexico, in Recent Sediments Northwest Gulf of Mexico, Shepard, F. P. (ed.), Am. Assoc. Petr. Geol. Pub., 394 pp.

Perkins, R. D., and Halsey, S. D., 1971, Geologic significance of microboring fungi and algae in Carolina shelf sediments, Jour. Sed. Pet., v. 41, p. 843-853.

Peterson, C. G. J., 1914, Valuation of the Sea. II, Animal communities of the sea bottom and their importance for marine zoogeography, Danish Biol. Stat. Rept., v. 21, 68 pp.

Pilkey, O. H., 1964, The size distribution and mineralogy of the carbonate fraction of United States South Atlantic shelf and upper slope sediments, Mar. Geol., v. 2, p. 121-136.

Pilkey, O. H., and Field, M. E., 1972, Onshore transportation of continental shelf sediment: Atlantic southeastern United States, in Shelf Sediment Transport, Swift, D. J. P., et al. (eds.), Dowden, Hutchinson, and Ross, Stroudsburg, Pa., 656 pp.

Pilkey, O. H., et al., 1969, Aspects of carbonate sedimentation of the Atlantic continental shelf of the southern United States, Jour. Sed. Pet., v. 39, p. 744-768.

Pulley, T. E., 1952, An illustrated check list of the marine mollusks of Texas, Texas Jour. Sci., v. 4, p. 167-199.

Schafer, W., 1972, Ecology and Palaeoecology of Marine Environments, Oliver and Boyd, Edinburgh, 568 pp.

Seilacher, A., 1964, Biogenic sedimentary structures, in Approaches to Paleoecology, Imbrie, J., and Newell, N. (eds.), John Wiley and Sons, New York, N. Y., 432 pp.

Sheldon, R. W., 1965, Fossil communities with multimodal size-frequency distributions, Nature, v. 206, p. 1336-1338.

Shields, A., 1936, Anwedung der Ahnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebewegung, Mitt Preus. Versuchanst. f. Wasserbau u. Schiffbau, Berlin, v. 26.

Shumway, G. G., et al., 1961, Submerged forest of mid-Wisconsin age off Panama City, Florida, Geol. Soc. Am. Spec. Paper, n. 68, p. 271.

Siegle, S., 1956, Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill, New York, N. Y., 312 pp.

Smith, M., 1951, East Coast Marine Shells, Edwards Brothers, Inc., Ann Arbor, Mich., 314 pp.

Smith, J. D., and Hopkins, T. S., 1972, Sediment transport on the continental shelf off Washington and Oregon in light of recent current measurements, in Shelf Sediment Transport, Swift, D. J. P., et al. (eds.), Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., 656 pp.

Snedecor, G. C., and Cochran, W. G., 1967, Statistical Methods, Iowa State Univ. Press, Ames, Iowa, 592 pp.

Sternberg, R. W., 1967, Measurements of sediment movement and ripple migration in a shallow marine environment, Mar. Geol., v. 5, p. 195-205.

_____, 1972, Predicting initial motion and bedload transport of sediment particles in the shallow marine environment, in Shelf Sediment Transport, Swift, D. J. P., et al. (eds.), Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., 656 pp.

Sternberg, R. W., and McManus, D. A., 1972, Implications of sediment dispersal from long-term, bottom current measurements on the continental shelf of Washington, in Shelf Sediment Transport, Swift, D. J. P., et al. (eds.), Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., 656 pp.

Straaten, L. M. J. U. van, 1952, Biogene textures and the formation of shell beds in the Dutch Wadden Sea, Koninkl. Ned. Akad. Wetensch. Ser. B., v. 55, p. 500-516.

_____, 1956, Composition of shell beds, formed in tidal flat environment in the Netherlands and in the Bay of Arcachon (France), Geol. en Mijnbouw.

Sundborg, A., 1956, The River Klaralven: a study of fluvial processes, Geograf. Ann., v. 38, p. 127-316.

Swift, D. J. P., 1970, Quaternary shelves and the return to grade, Mar. Geol., v. 8, p. 5-30.

Swift, D. J. P., et al., 1971, Relict sediments on continental shelves: a reconsideration, Jour. Geol., v. 79, p. 322-346.

_____, 1972, Shelf sediment transport: a probability model, in Shelf Sediment Transport, Swift, D. J. P., et al. (eds.), Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., 656 pp.

Tanner, W. F., 1959, Nearshore studies in sedimentology and morphology along the Florida panhandle coast, Jour. Sed. Pet., v. 29, p. 564-574.

_____, 1960, Florida coastal classification, Gulf Coast Assoc. Geol. Soc. Trans., v. 10, p. 259-266.

_____, 1962, Nearly ideal drift system along Florida panhandle coast (abst.), Geol. Soc. Am. Spec. Paper, n. 73, p. 311.

Taylor, J. D., and Layman, M., 1972, The mechanical properties of bivalve (Mollusca) shell structures, Palaeontology, v. 15, p. 73-87.

Thorson, G., 1957, Bottom communities (sublittoral or shallow shelf), in Treatise on Marine Ecology and Paleoecology, v. 1, Hedgepeth, J. W. (ed.), Geol. Soc. Am. Mem., n. 67, 1296 pp.

Trenhaile, A. S., 1973, Near-shore ripples: some hydraulic relationships, Jour. Sed. Pet., v. 43, p. 558-568.

Trewin, N. H., and Welsh, W., 1972, Transport, breakage and sorting of the bivalve Mactra corallina on Aberdeen Beach, Scotland, Palaeogeogr., Palaeoclim., Palaeoecol., v. 12, p. 193-204.

Valentine, J. W., 1961, Paleoecologic molluscan geography of the California Pleistocene, Univ. Calif. Pub. Geol. Sci., v. 34, p. 309-442.

_____, 1973, Why 'communities' - comment, Geology, v. 1, p. 59-60.

Vause, J. E., 1959, Underwater geology and analysis of Recent sediments off the northwest Florida coast, Jour. Sed. Pet., v. 29, p. 555-563.

Vernon, R. O., 1942, Geology of Holmes and Washington Counties, Florida, Florida Geol. Surv. Geol. Bull., n. 21, 161 pp.

Vernon, R. O., and Puri, H. S., 1964, Geologic map of Florida, Florida Geol. Surv. Map. Ser., n. 18.

Warme, J. E., 1969, Live and dead mollusks in a coastal lagoon, Jour. Paleo., v. 43, p. 141-150.

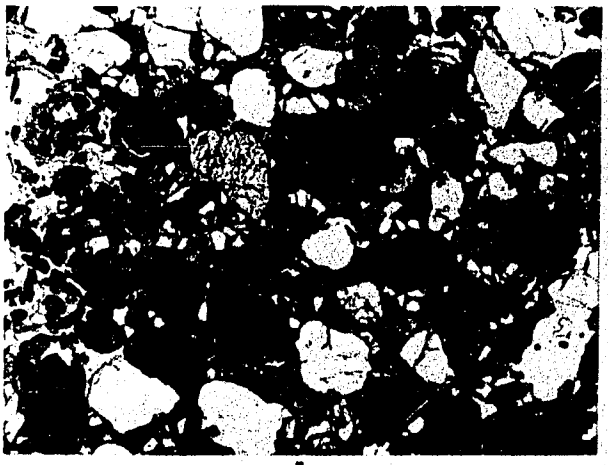
_____, 1971, Paleoecological Aspects of a Modern Coastal Lagoon, Univ. Calif. Pub. Geol. Sci., v. 87, 131 pp.

Wilson, J. B., 1967, Paleoecological studies on shell beds and associated sediments in the Solway Firth, Scottish Jour. Geol., v. 3, p. 329-371.

PLATE 1

Quartzose Lime Grainstone

1. Photomicrograph of the quartzose lime grainstone in thin section (x9), plain light. Large, rounded, dark grains are coralline algal fragments. Smaller biogenic detritus between the quartz grains and algal fragments consists of Foraminifera, echinoid and molluscan shell fragments.
2. As above, X-nicols. Two quartz grain size modes are present: 1) very coarse subangular to rounded grains, and 2) fine angular grains.
3. Photomicrograph of the quartzose lime grainstone in thin section (x9), plain light. Quartz grains and biogenic debris cemented by low-magnesian calcite.
4. As above, X-nicols.
5. Scanning electron microscope photomicrograph of the low-magnesian calcite cement of scalenohedral crystal habit (x800).



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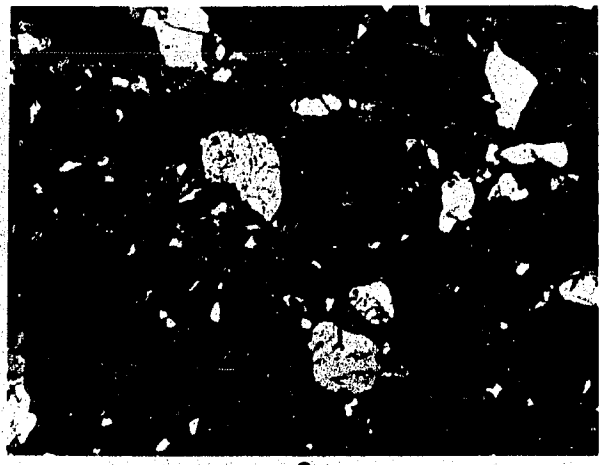

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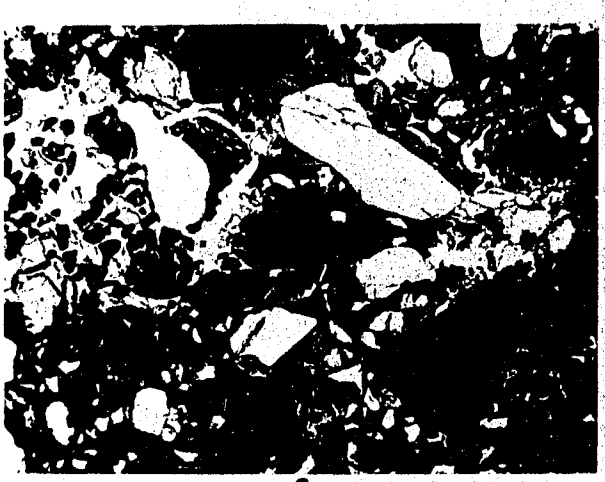

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PLATE 2

Relict Bivalve Assemblage

1. Noetia ponderosa (x.53): a. interior, b. exterior.
2. Anadara ovalis (x.89): a. interior, b. exterior.
3. Trachycardium muricatum (x.76): a. interior, b. exterior.
4. Trachycardium egmontianum (x.43): a. interior, b. exterior.
5. Chione cancellata (x1.0): a. interior, b. exterior.
6. Mactra fragilis (x.43): a. interior, b. exterior.
7. Mercenaria campechiensis (x.33): a. interior, b. exterior.
8. Mulinia lateralis (x2.7): a. interior, b. exterior.
9. Brachidontes exustus (x2.3): a. interior, b. exterior.
10. Spisula solidissima (x1.0): a. interior, b. exterior.
11. Cumingia tellinoides (x2.7): a. interior, b. exterior.
12. Cardita floridana (x1.5): a. interior, b. exterior.
13. Donax variabilis (x1.8): a. interior, b. exterior.
14. Glycymeris pectinata (x1.4): a. interior, b. exterior.
15. Laevicardium mortoni (x2.4): a. interior, b. exterior.

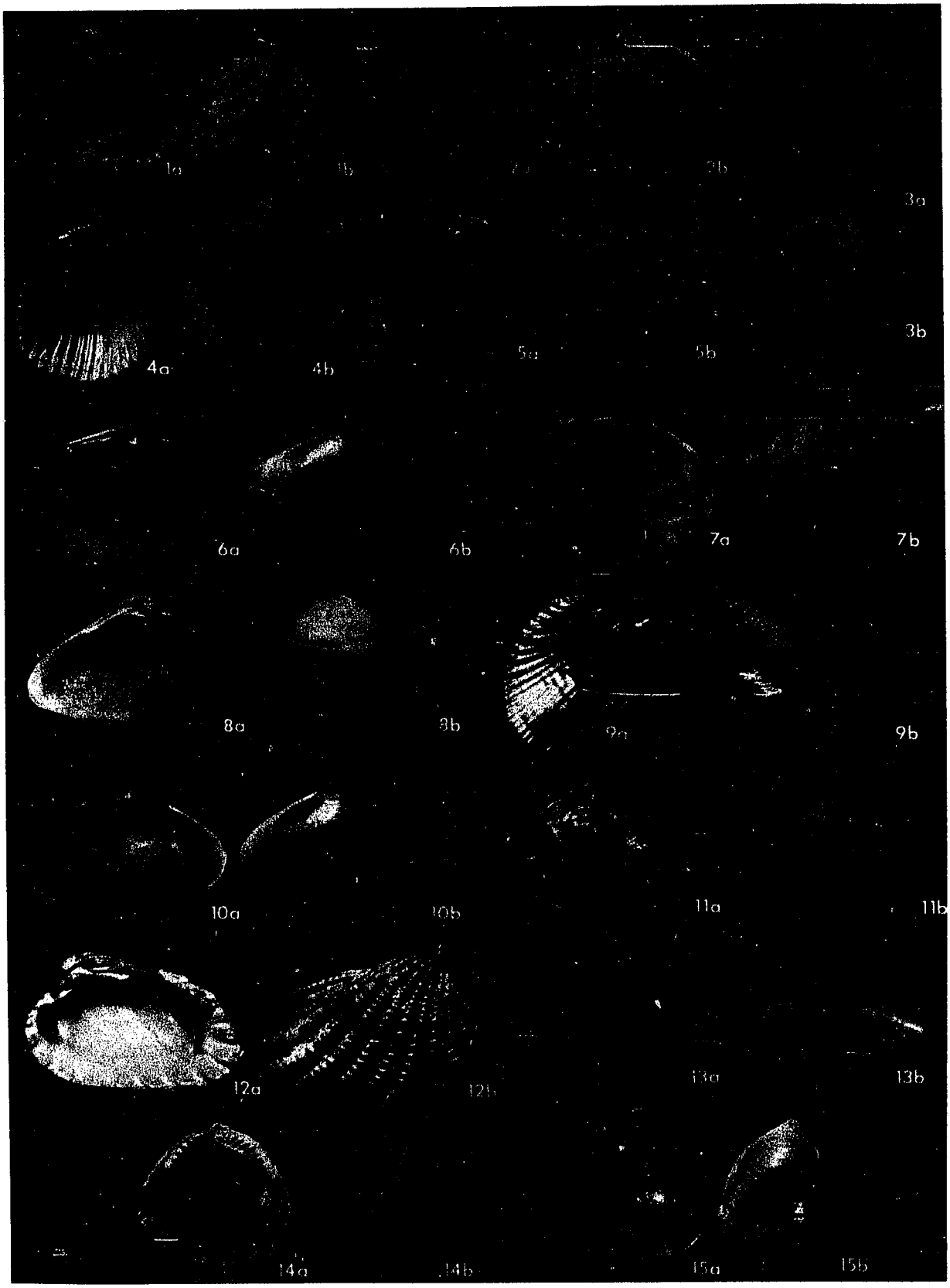
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PLATE 3

Relict Gastropod Assemblage

1. Anachis avera semiplicata (x3.4): aperture.
2. Pyramidella crenulata (x3.4): aperture.
3. Prunum apicinum (x4.1): aperture.
4. Modulus modulus (x3.4): a. apex, b. aperture.
5. Turbo castaneus (x1.3): aperture.

Nearshore Assemblage

6. Donax variabilis (x5.1): a. interior, b. exterior.
7. Olivella mutica (x6.2): aperture.
8. Terebra cinerea (x1.2): aperture.
9. Mellita quinquiesperforata (x.45): aboral.

Shoreface and Offshore Sand Plain Assemblage

10. Macrocallista nimbosa (x.29): a. exterior, b. interior.
11. Lucina radians (x1.2): a. interior, b. exterior.
12. Strigilla mirabilis (x3.3): a. interior, b. exterior.
13. Cavilucina trisulcatus (x4.7): a. interior, b. exterior.
14. Ervilia concentrica (x7.8): a. interior, b. exterior.
15. Dinocardium robustum (x.62): a. interior, b. exterior.
16. Lucina multilineata (x7.0): a. interior, b. exterior.
17. Pandora trilineata (x2.0): a. interior, b. exterior.

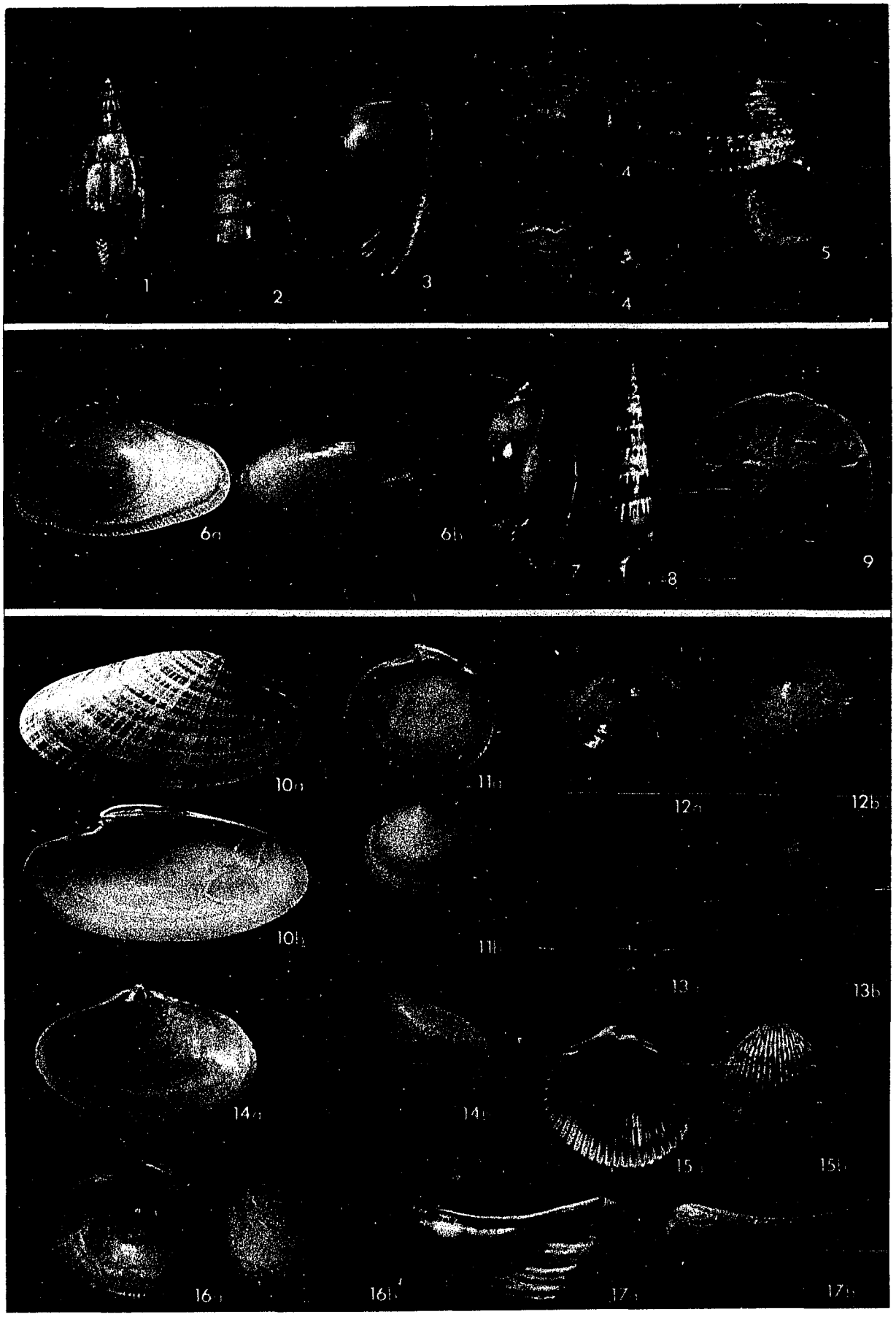
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PLATE 4

Offshore Sand Plain Assemblage

1. Varicorbula operculata (x3.8): a. interior, b. exterior.
2. Corbula krebsiana (x5.3): a. interior, b. exterior.
3. Laevicardium laevigatum (x.53): a. interior, b. exterior.
4. Laevicardium pictum (x2.7): a. interior, b. exterior.
5. Plicatula gibbosa (x2.3): a. exterior, b. interior.
6. Macrocallista maculata (x.53): a. interior, b. exterior.
7. Anomia simplex (x5.0): exterior.
8. Pandora arenosa (x3.0): a. interior, b. exterior.
9. Crassinella lunulata (x8.3): a. interior, b. exterior.
10. Scapharca transversa (x4.0): a. interior, b. exterior.
11. Chione intapurpurea (x.8): a. interior, b. exterior.
12. Venericardia tridentata (x5.4): a. interior, b. exterior.
13. Aequipecten gibbus (x.59): a. interior, b. exterior.
14. Tellina sp. (x5.7): a. interior, b. exterior. This species is typical of the group Tellina spp. in this report.
15. Transennella sp. (x5.3): a. interior, b. exterior.

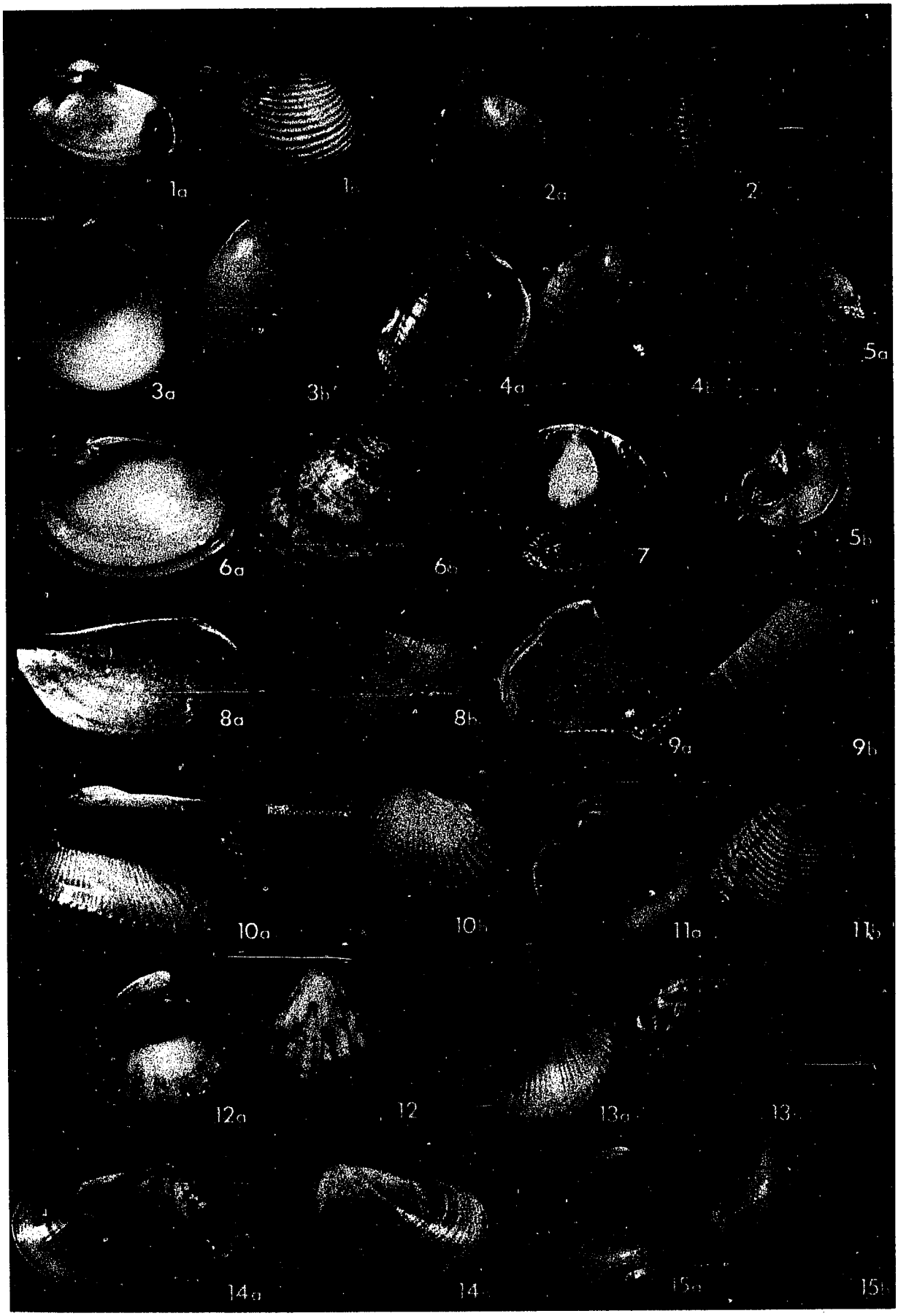
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PLATE 5

Offshore Sand Plain Assemblage

1. Corbula dietziana (x3.9): a. exterior, b. interior.
2. Corbula barrattiana (x7.2): a. exterior, b. interior.
3. Chione grus (x6.5): a. exterior, b. interior.
4. Corbula swiftiana (x6.2): a. interior, b. exterior.
5. Diplodonta punctatus (x2.6): a. interior, b. exterior.
6. Crepidula aculeata (x2.2): apex.
7. Crepidula plana (x2.6): aperture.
8. Crepidula fornicata (x2.2): aperture.
9. Calyptraea centralis (x5.1): apex.
10. Polinices duplicatus (x1.1): aperture.
11. Polinices lacteus (x5.0): aperture.
12. Natica cf. N. pusilla (x5.9): aperture.
13. Oliva sayana (x.6): aperture.
14. Olivella floralia (x5.0): aperture.
15. Cerithium floridanum (x.9): aperture.
16. Terebra concava (x1.0): aperture.
17. Terebra dislocata (x.8): aperture.
18. Discoporella umbellata (x5.0): top zoarium.
19. Dentalium eboreum (x1.1).
20. Neogoniolithon sp. (x1.5).
21. Encope aberrans (x.28): aboral.
22. Encope michelini (x.28): aboral.

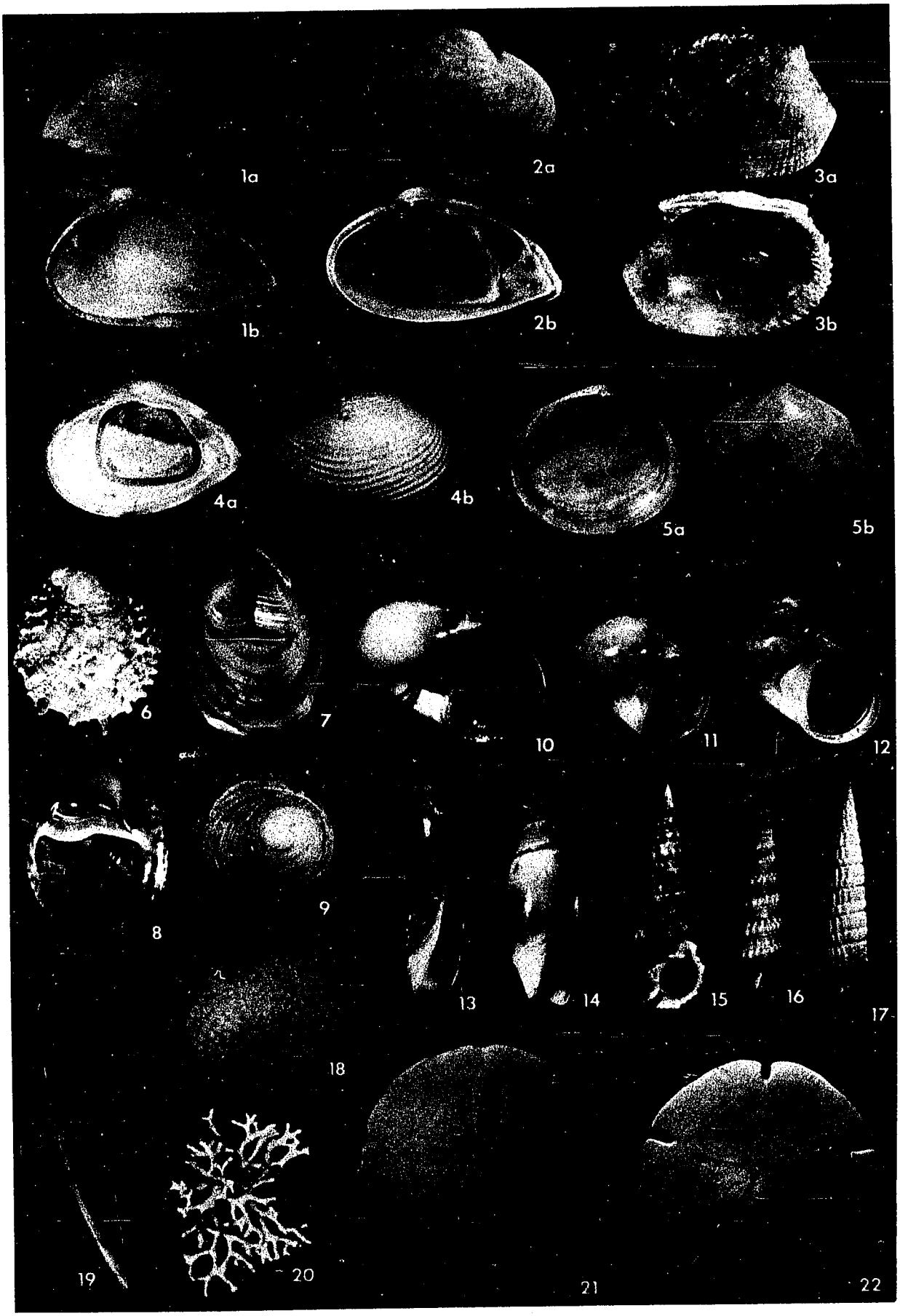
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PLATE 6

Offshore Sand Plain Assemblage

1. Plagiobrissus grandis (adult) (x.33): a. oral, b. aboral.

Limestone Substrate Assemblage

2. Arca zebra (x.9): a. exterior, b. interior.

3. Arca umbonata (x.67): a. exterior, b. interior.

4. Pteria colymbus (x.67): exterior.

5. Barbatia domingensis (x2.1): a. exterior, b. interior.

6. Arcopsis adamsi (x5.3): a. exterior, b. interior.

7. Chama congregata (x2.5): a. interior, b. exterior.

8. Scapharca transversa (x1.5): a. interior, b. exterior.

9. Barbatia tenera (x3.0): a. exterior, b. interior.

10. Lithophaga bisulcata (x1.5): a. exterior, b. interior.

11. Chione grus (x6.5): a. interior, b. exterior.

12. Diodora cayenensis (x3.2): apex.

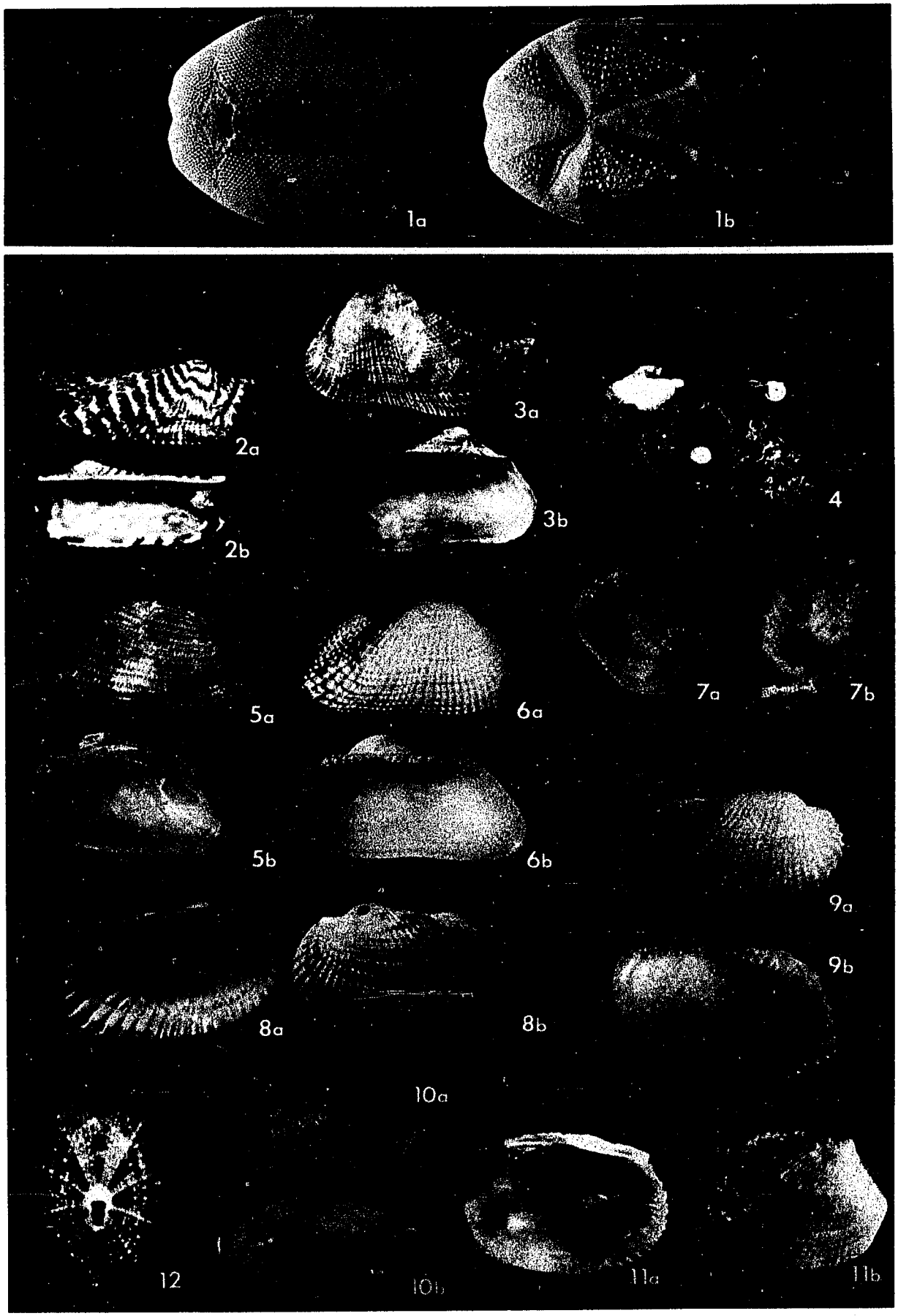
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PLATE 7

Preservation Types

1. Fresh valve of Scapharca transversa (x6.5).
2. Slightly corraded valve of Scapharca transversa (x5.0). Note the loss of luster and slight deterioration of shell surface.
3. Moderately corraded valve of Scapharca transversa (x5.0). Note the pitted surface and recognizable hinge structure and marginal denticulation.
4. Severely corraded valve of Scapharca transversa (x4.5) characterized by loss of hinge structures and ornamentation and deeply pitted surface.
5. Comparison of moderately (above) and severely corraded (below) appearence of exterior valve surface, Scapharca transversa.
6. Encope michelini test collected near the limestone outcrop showing the probable effect of solution in the exposure of the interior canal system (x.6).

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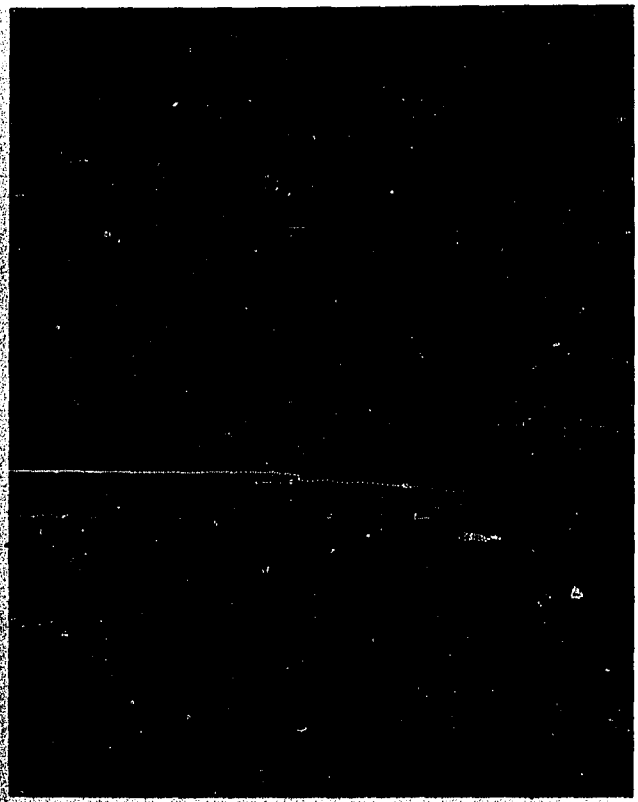

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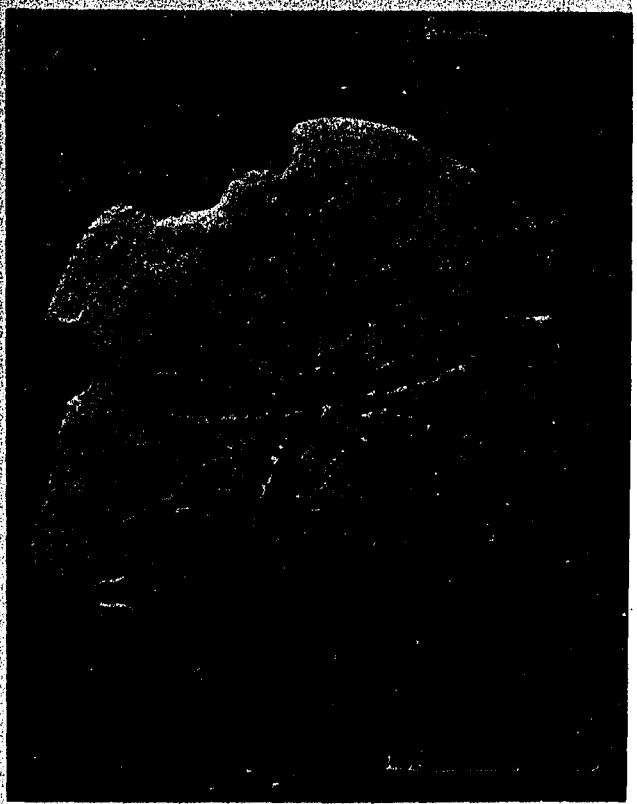

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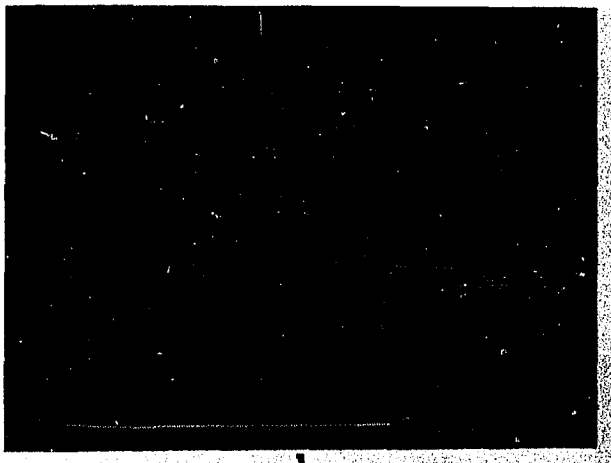
PLATE 8

Lower Shoreface

1. Bioturbated fine sand of the lower shoreface. Pits and mounds are primarily of the enteropneust Balanoglossus sp. Surface mottling results from disturbance of an algal/benthic diatom(?) surface film and advection of subsurface sand to the surface.
2. Castings mound of Balanoglossus sp. consisting of excreted, mucus-rich sand. Mound is approximately 6 inches across.
3. Encope michelini burrowing in near-surface sand. Broad locomotory trail is visible amoung the pits and castings of Balanoglossus sp.
4. Encope aberrans and burrowing trail. The anal lunule is clearly seen. Astropecten articulata, upper center, is the most common asteroid of the lower shoreface. Note the incipient oscillation ripples and removal of algal film, lower left.
5. Luidia alternata, uncommon on the lower shoreface. Also visible are linear locomotory trails of gastropods and trails of Encope spp. Star is about 7 inches across.
6. Vertical wall of a sampling excavation showing closely spaced mucous tubes of the polychaete Lumbrineris inflata. Longest tube measures 3 inches. Surface algal film extends into grain interstices to form a thin mat. Shell fragments constitute a very small percentage of the sediment.



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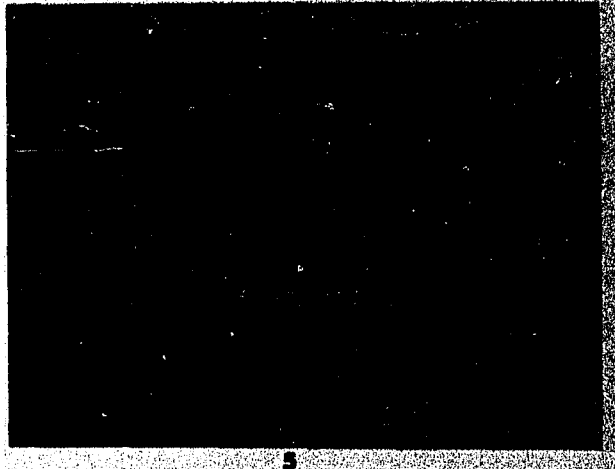

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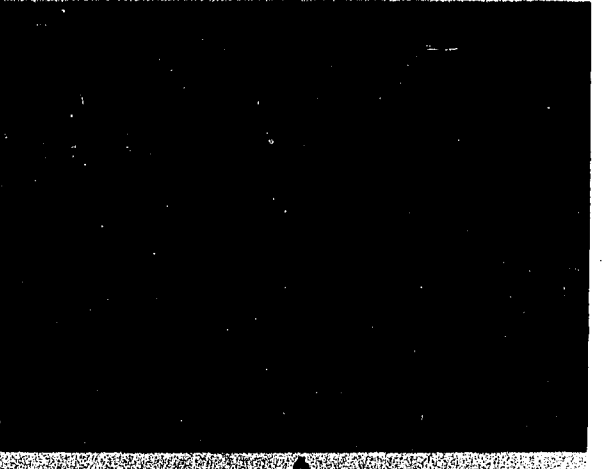

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PLATE 9

Offshore Sand Plain

1. Hummocky surface of the coarse sand is densely burrowed by Plagiobrissus grandis. An empty test of P. grandis is seen, upper center. The asteroid is Echinaster modestus, a common species of the offshore sand plain. The broad linear trail, lower left, is of the gastropod Sinum perspectivum. The star is about 4 inches across.
2. Large-scale ripple crest (diagonal, lower right to upper left) with castings mound of Balanoglossus sp., center. The sand surface is mottled by the burrowing activity of unidentified invertebrates.
3. Sand surface intensely bioturbated by horizontal and vertical burrow systems. Dark color of undisturbed sand is due to a surface film of algae and benthic diatoms(?).
4. As above. Star-shaped burrow, probably of Luidia clathrata, upper center, is 7 inches across.
5. Ripple crests (light) and troughs (dark) subdued by intense biologic activity. Ripple wavelength is about 3 feet.
6. As above. Horizontal locomotory trails of Encope spp. destroy ripple crests in the foreground.

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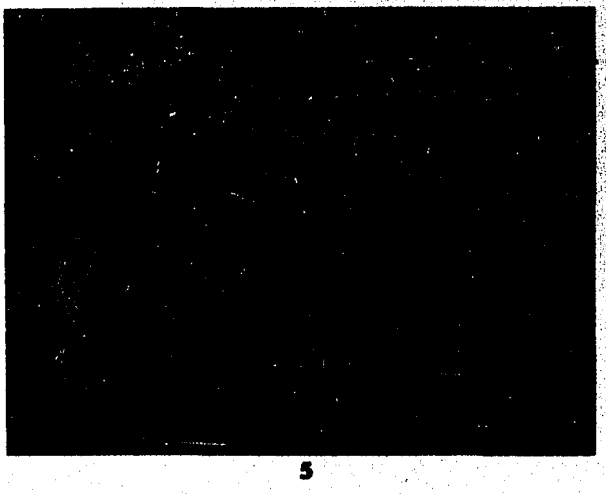

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PLATE 10

Offshore Sand Plain

1. Large-scale sand oscillation ripples, wavelength about 3 feet, at location S-1 northwest of the limestone outcrop. Polychaete tubes, primarily of Onuphis eremita oculata, are exposed in the ripple troughs indicating recent sediment movement.
2. Detail of exposed polychaete tubes at location S-1. Tubes project up to 1 inch above the sediment surface. Note the fish nest in the foreground.
3. A common tube-dwelling anemone, left of center, among exposed polychaete tubes.
4. Ripple troughs and crests aligned parallel to the coast, location S-1. Excavation, center, reveals large relict shells (Mercenaria campechiensis) beneath sand surface.
5. The large star Luidia clathrata, partially buried. Tests of Plagiobrissus grandis, upon which the starfish prey, are scattered about. The star is about 8 inches across.
6. Star-shaped resting traces of Luidia clathrata and linear locomotory burrows, possibly of the gastropod Oliva sayana. Onuphis magna tubes project from the sand, lower left.

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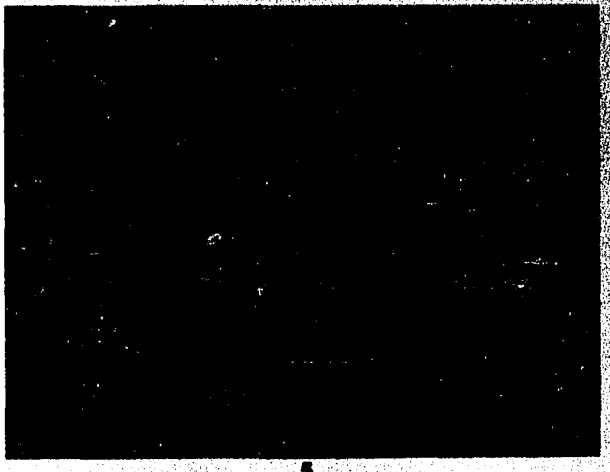

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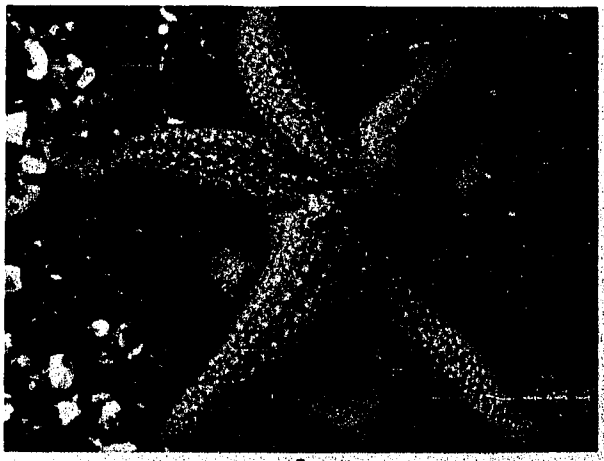
PLATE 11

Offshore Sand Plain

1. Echinaster modestus feeding on a juvenile Plagiobrissus grandis. Starfish is about 4 inches across.
2. Empty tests of Plagiobrissus grandis resting on the coarse sand surface. Tests are about 3 inches in length.
3. Nest of an unknown species of fish. Biogenic fragments include those of mollusks, Plagiobrissus grandis, Neogoniolithon sp., and Encope spp.
4. A living Neogoniolithon sp. plant, center, resting in growth position on the sand surface (x.25).
5. Tubes of the large polychaete Onuphis magna project 1 to 2 inches above the sand surface. Sponges and small growths of Bugula neritina encrust the exposed portions of the tubes.
6. Vertical wall of a sampling excavation showing the coherent nature of the surface sand bound by algal growth and vertical mucous tubes of Lumbrineris inflata. Tubes are about 4 inches long. Biogenic material constitutes a significant percentage of the sediment.



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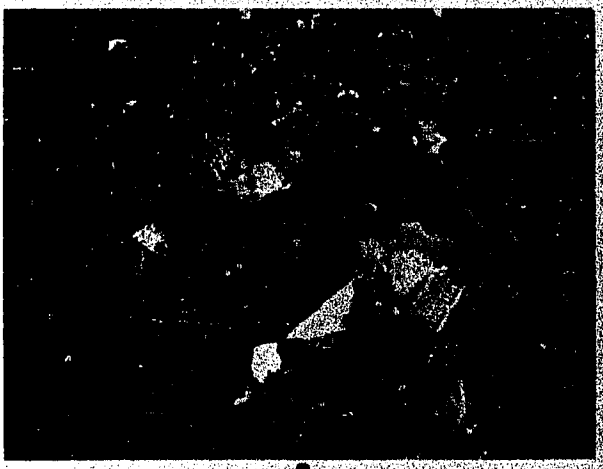

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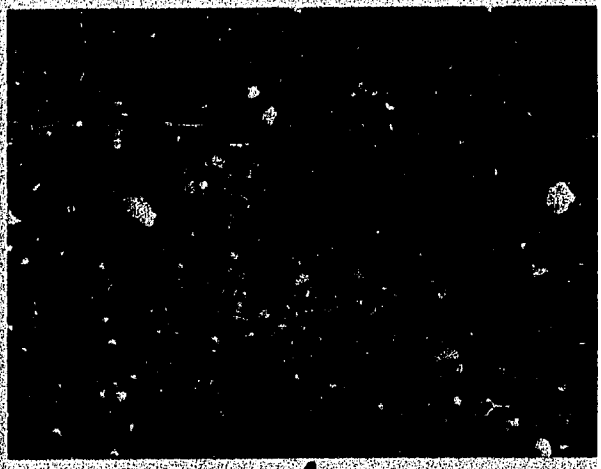

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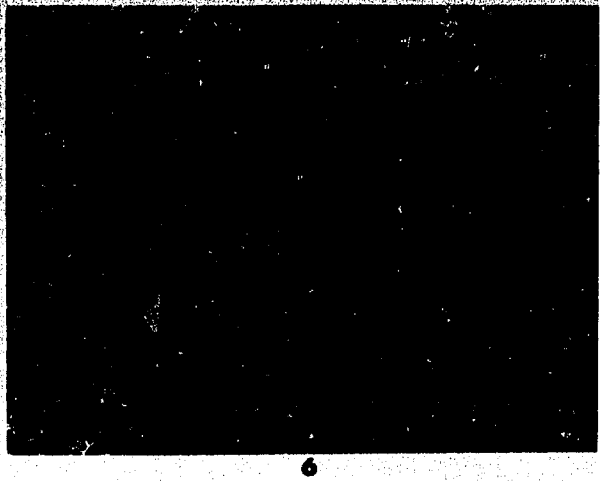

6

PLATE 12

Offshore Sand Plain

1. Egg cluster, probably of the gastropod Phalium granulatum, attached at the base to a large shell fragment. The cluster is about 8 inches high. Ripple crests in the background are modified by biologic activity.
2. A broken shell of Strombus pugilus inhabited by barnacles, Crepidula fornicata, and a small fish. The shell is about 5 inches in length.
3. A juvenile Plagiobrissus grandis (x.5) burrowing into the sand by movement of ventral and peripheral spines.
4. The conical burrow of Plagiobrissus grandis. Tips of the dorsal spines are visible at the base of the cone.

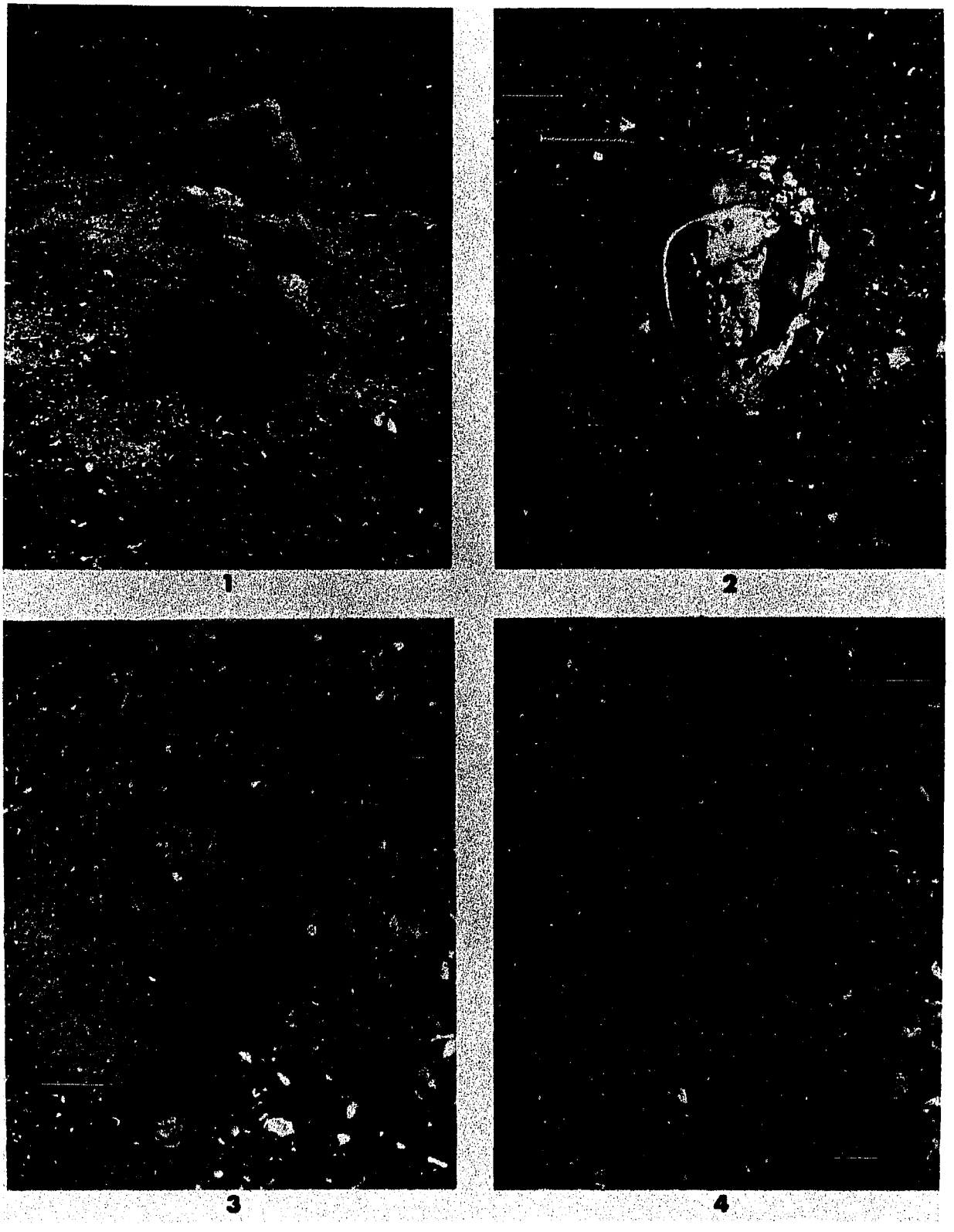
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PLATE 13

Limestone Outcrop

1. Limestone ledge, about 1.5 feet high. The rock surface is densely inhabited by many sessile epibenthic species. Sediment in the foreground consists of coarse quartz sand and shells and shell fragments.
2. Detail of encrusted limestone surface. Sessile organisms in this photograph include green algae, bryozoans, colonial hydrozoans, scleractinian corals, and encrusting sponges. Small polyps visible in the foreground are those of Phyllangia americana.
3. The alcyonarians Lophogorgia hebes (background) and Leptogorgia virgulata (foreground) attached to small limestone projections in the surrounding coarse sand. Knife blade is 7 inches in length.
4. Limestone rubble surrounded by coarse grained biogenic and clastic sediment.
5. Arbacia punctulata, center, grazing on epibenthic organisms on the limestone rubble. Note abundant shell material between the limestone blocks. The shell of Pteria colymbus, right foreground, is about 2.5 inches long.
6. Large shells and fragments of relict bivalve species. Largest shells (left of knife) are those of Mercenaria campechiensis. The echinoid Lytechinus variegatus is seen, lower left foreground.

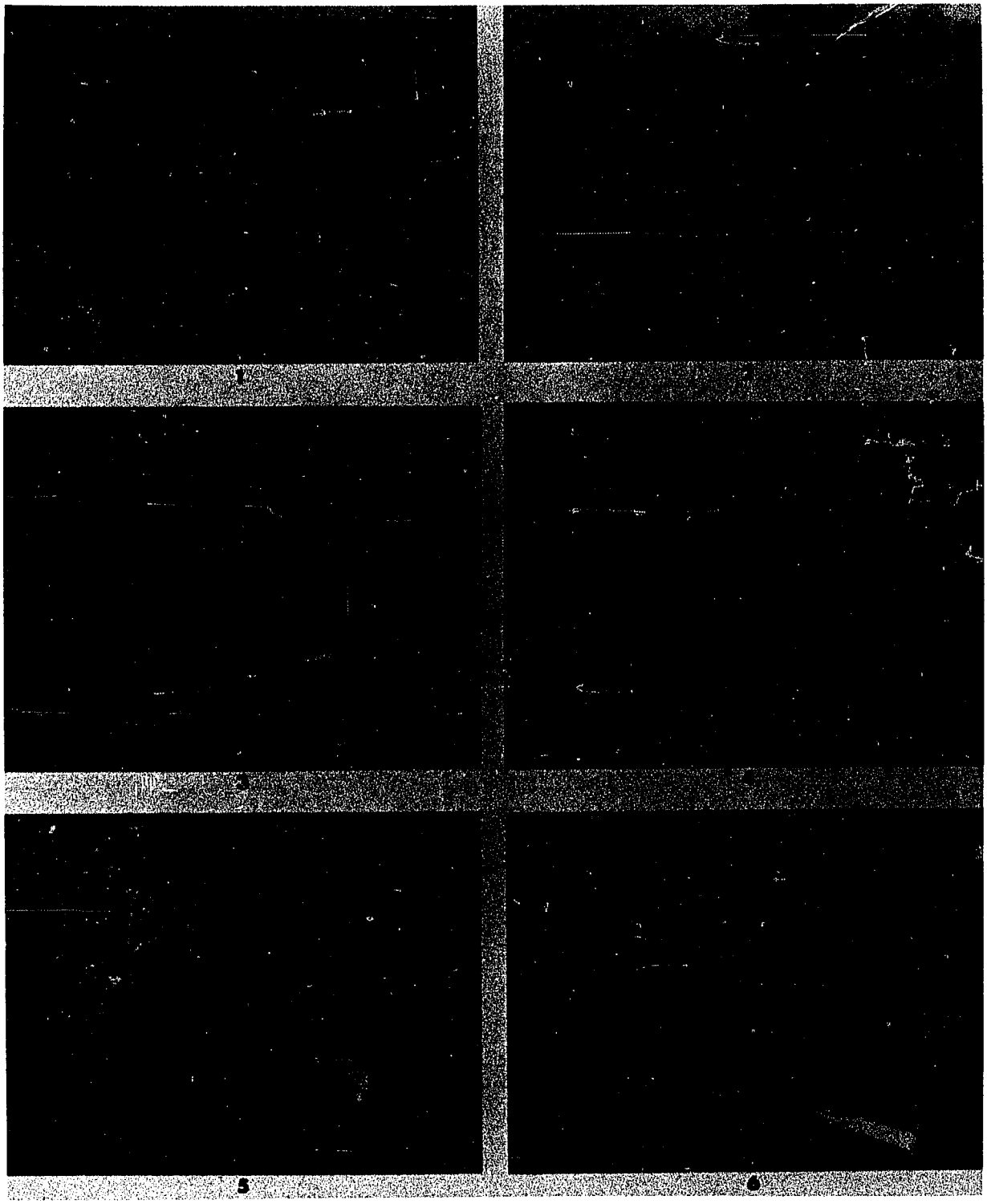
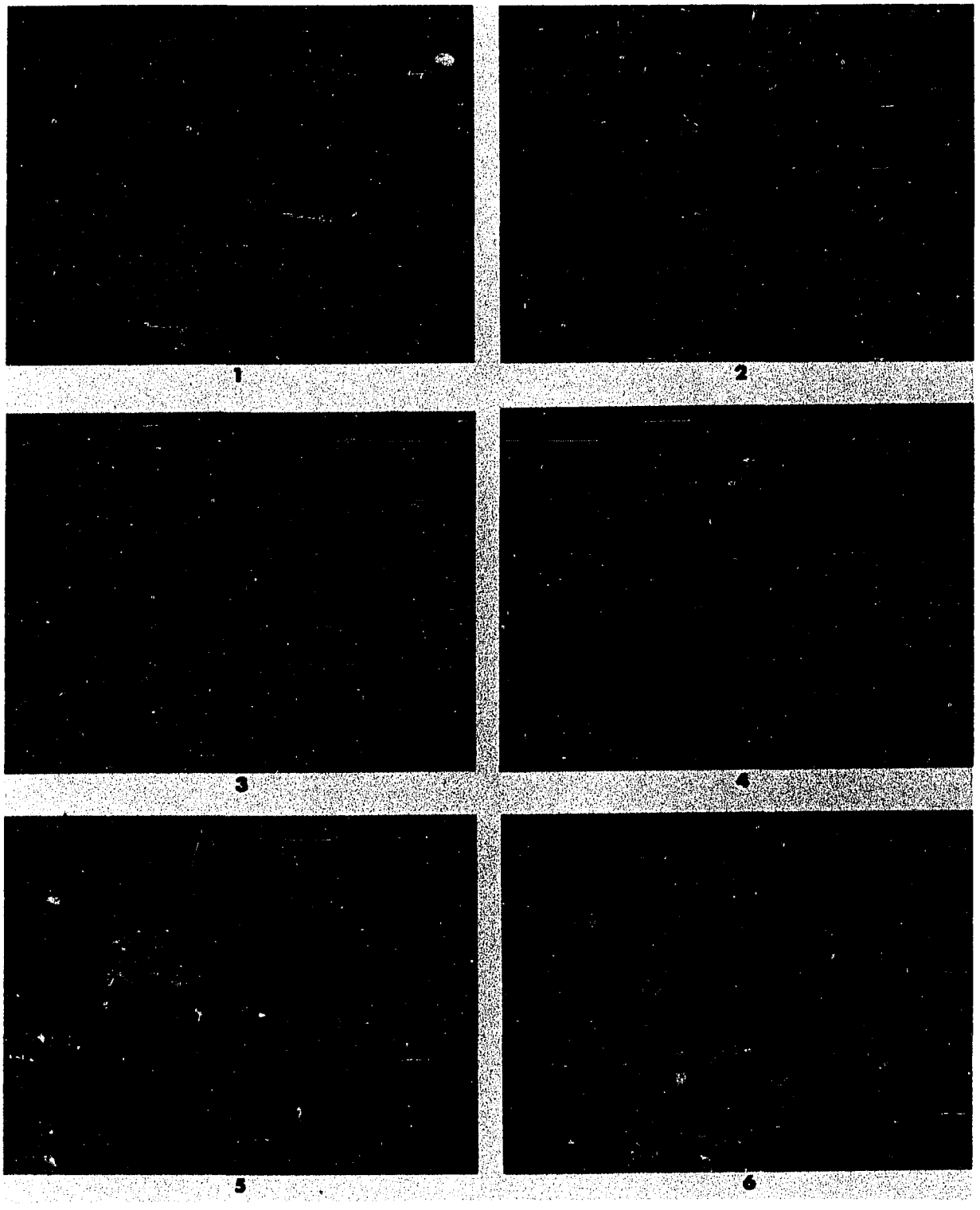


PLATE 14

Limestone Outcrop

1. Moray eel inhabits a hole under a limestone block, center. The star Echinaster braziliensis is visible, upper center, and alcyonarians, lower right.
2. Limestone ledge encrusted by the sponge Placospongia carinata, center. Polyps of Phyllangia americana are also seen in the foreground.
3. Limestone rubble and coarse shell debris. Rock surface is inhabited by a dense aggregation of Arca umbonata.
4. Pteria colymbus in growth position on Lophogorgia hebes. Note the intergrowth of barnacles, Bryozoa, and encrusting algae on the valve exterior. The shell is about 3 inches in length.
5. A small head of the scleractinian Solenastrea hyades attached at the base to a limestone projection and surrounded by coarse skeletal debris, quartz sand, and limestone fragments.
6. The echinoid Lytechinus variegatus typically decorated with large shells and, in this case, a living colonial ascidian. Relict valve of Mercenaria campechiensis is seen to the left of the echinoid.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APPENDIX A

PROCEDURE FOR LOCATION OF LIMESTONE OUTCROP

Stand off Crystal Beach Pier about 1.5 miles. Look to the east and observe 6 low, white, circular structures. These are the large buildings of a road-side rest area. On the horizon above the rest area observe a large tree whose crown projects above the surrounding foliage. Proceed to the east until the tree is centered between the second and third white structure counting from the left. Proceed directly toward the tree keeping it centered. Look to the west toward Destin and locate the tall red-topped water tower. As you proceed toward the coast it will appear to move behind the cylindrical Quality Court Motel. As it reappears on the north side of the Quality Court Motel prodeed slowly. When the water tower is centered between the Quality Court Motel and the next square building to the north, anchor. Dive to the anchor which should be located about 50 feet west of line RL1.

APPENDIX B

SEDIMENT TEXTURAL STATISTICS

	MOMENT MEASURES					GRAPHICAL STATISTICS			
	ØM	S^2	S	Sk_1	K_1	M_z	Sort	Sk_2	K_2
L111	1.647	0.8208	0.906	-0.429	2.210	0.675	0.845	-0.121	1.153
L112	0.632	0.9858	0.993	-0.524	2.611	0.675	0.905	-0.159	1.159
L121	-	-	-	-	-	2.177	0.678	-0.151	1.347
L122	-	-	-	-	-	2.163	0.658	-0.132	1.350
L131	1.629	0.6269	0.792	-0.831	7.004	1.654	0.693	-0.246	1.088
L132	1.808	0.4395	0.663	-0.534	3.800	1.838	0.609	-0.167	1.191
L141	1.364	0.4486	0.670	-0.420	3.828	1.368	0.627	-0.085	0.917
L142	1.346	0.4697	0.685	-0.245	1.512	1.349	0.654	-0.072	0.887
L151	1.253	0.3830	0.619	-0.145	1.871	1.262	0.595	0.013	0.951
L152	1.184	0.4182	0.647	-0.384	4.971	1.198	0.593	0.039	0.971
L161	1.256	0.3604	0.600	-0.041	0.712	1.262	0.585	0.019	0.964
L162	1.222	0.4537	0.674	-0.491	6.421	1.239	0.602	0.025	0.986
L171	1.368	0.2712	0.521	0.073	1.734	1.364	0.495	0.082	1.115
L172	1.380	0.3354	0.579	-0.376	7.226	1.385	0.524	0.090	1.136
L181	1.555	0.2364	0.486	0.192	1.351	1.536	0.469	0.160	1.148
L182	1.555	0.2462	0.496	0.163	1.387	1.539	0.474	0.161	1.158
L191	2.143	0.2904	0.539	-0.390	1.788	2.153	0.521	-0.146	1.070
L192	2.053	0.2869	0.536	-0.301	1.039	2.060	0.524	-0.141	1.012
L211	0.977	0.5256	0.725	-0.138	2.539	0.995	0.689	0.126	1.070
L212	0.888	0.5390	0.734	-0.429	4.900	0.916	0.650	0.099	1.156
L221	1.112	0.4602	0.678	-0.170	1.978	1.129	0.641	0.030	1.028
L222	1.147	0.5202	0.721	-0.199	2.249	1.164	0.673	0.031	0.997
L231	1.124	0.5001	0.707	-0.189	2.001	1.140	0.669	0.023	0.989
L232	1.194	0.4363	0.661	-0.022	1.174	1.199	0.638	0.058	0.999
L241	1.206	0.4239	0.651	-0.116	2.042	1.209	0.616	0.025	1.016
L242	1.264	0.4268	0.653	-0.063	1.446	1.283	0.630	0.030	1.012
L251	1.248	0.3779	0.615	-0.083	1.762	1.250	0.587	0.020	1.023
L252	1.239	0.4028	0.635	0.012	1.469	1.235	0.610	0.047	1.023
L261	1.311	0.4256	0.652	0.016	1.275	1.302	0.639	0.058	1.031
L262	1.313	0.5126	0.716	-0.164	3.397	1.303	0.689	0.077	1.024
L271	1.334	0.3703	0.608	0.191	0.564	1.324	0.599	0.145	1.043
L272	1.400	0.3908	0.625	0.160	0.432	1.387	0.618	0.140	1.038
L281	1.345	0.4009	0.633	0.081	1.321	1.338	0.615	0.141	1.059
L282	1.383	0.3963	0.609	-0.010	2.614	1.372	0.606	0.113	1.054
L291	2.043	0.4212	0.649	-0.283	0.147	2.050	0.655	-0.201	0.975
L292	1.931	0.4659	0.682	-0.226	-0.053	1.950	0.689	-0.165	0.927

	MOMENT MEASURES					GRAPHICAL STATISTICS			
	ØM	S^2	S	Sk_1	K_1	M_z	Sort	Sk_2	K_2
L111A	0.864	0.5038	0.710	-0.065	0.771	0.871	0.686	-0.003	1.057
L112A	0.891	0.5133	0.716	-0.112	0.872	0.908	0.689	-0.001	1.080
L121A	2.228	0.3685	0.607	-0.379	1.633	2.262	0.572	-0.057	1.229
L122A	2.184	0.3446	0.587	-0.379	1.695	2.208	0.559	-0.071	1.217
L131A	1.694	0.4434	0.666	-0.227	0.165	1.697	0.665	-0.224	1.071
L132A	1.829	0.3537	0.595	-0.253	0.780	1.842	0.584	-0.164	1.227
L141A	1.400	0.3968	0.630	-0.081	-0.074	1.391	0.636	-0.087	0.911
L142A	1.366	0.4178	0.646	-0.022	-0.233	1.355	0.652	-0.066	0.869
L151A	1.242	0.3601	0.600	-0.011	0.273	1.244	0.595	-0.004	0.944
L152A	1.198	0.3632	0.603	0.031	0.224	1.199	0.597	0.032	0.946
L161A	1.255	0.3505	0.592	-0.001	0.381	1.256	0.587	0.014	0.954
L162A	1.245	0.3759	0.613	0.008	0.503	1.249	0.600	0.031	0.974
L171A	1.363	0.2592	0.509	0.102	1.223	1.360	0.492	0.077	1.110
L172A	1.389	0.2758	0.525	0.144	0.970	1.387	0.513	0.108	1.139
L211A	1.007	0.4504	0.671	0.186	0.282	1.006	0.669	0.153	1.009
L212A	0.937	0.3987	0.631	0.143	0.508	0.934	0.625	0.115	1.079
L221A	1.141	0.4132	0.643	0.056	0.351	1.144	0.633	0.041	0.970
L222A	1.184	0.4411	0.664	0.092	0.216	1.181	0.659	0.047	0.943
L231A	1.152	0.4412	0.664	0.069	0.096	1.150	0.662	0.021	0.940
L232A	1.215	0.4052	0.637	0.109	0.259	1.209	0.628	0.067	0.953
L241A	1.223	0.3808	0.617	0.085	0.449	1.126	0.606	0.028	0.970
L242A	1.267	0.3929	0.627	0.087	0.254	1.257	0.624	0.036	0.971
L251A	1.263	0.3607	0.601	0.087	0.424	1.255	0.593	0.017	0.989
L252A	1.267	0.3823	0.618	0.124	0.439	1.257	0.613	0.037	1.010
L261A	1.331	0.4083	0.639	0.138	0.152	1.313	0.637	0.016	0.676
L262A	1.324	0.4631	0.681	0.162	0.067	1.299	0.685	0.074	1.012
L271A	1.339	0.3624	0.602	0.227	0.389	1.326	0.599	0.141	1.050
L272A	1.397	0.3873	0.622	0.182	0.183	1.383	0.621	0.124	1.020
35'L2	2.259	0.2216	0.471	-0.362	1.910	2.273	0.453	-0.093	1.234
25'L2	2.202	0.1921	0.438	-0.307	1.539	2.214	0.425	-0.089	1.206
BC	2.064	0.1590	0.399	-0.449	2.366	2.084	0.377	-0.116	1.123
T	1.911	0.2536	0.504	-0.336	0.990	1.924	0.495	-0.166	1.103
S-1	1.202	0.4004	0.633	0.174	2.027	1.180	0.594	0.126	1.146
S-2	0.813	0.7292	0.854	-0.609	3.969	0.869	0.757	-0.079	1.175
S-1A	1.197	0.3479	0.590	0.317	1.181	1.170	0.564	0.113	1.118
S-2A	0.987	0.4661	0.683	-0.160	1.675	1.001	0.653	0.031	1.030

	MOMENT MEASURES					GRAPHICAL STATISTICS			
	ØM	S^2	S	Sk_1	K_1	M_z	Sort	Sk_2	K_2
L112C	-0.461	0.1462	1.209	-0.314	0.637	-0.394	1.161	-0.248	1.211
L122C	1.548	0.1533	1.238	-0.559	1.206	1.605	1.200	-0.362	1.334
L132C	1.442	0.1091	1.045	-0.645	2.439	1.518	0.948	-0.273	1.463
L141C	1.087	0.1339	1.157	-0.760	2.888	1.164	1.028	-0.347	1.502
L151C	1.010	0.1512	1.230	-0.637	1.523	1.049	1.170	-0.435	1.611
L161C	1.140	0.1167	1.080	-0.553	1.491	1.137	1.042	-0.380	1.509
L171C	0.969	0.1356	1.165	-0.360	0.651	0.996	1.131	-0.222	1.180
L211C	0.454	0.1053	1.026	-0.549	2.592	0.504	0.927	-0.184	1.737
L221C	0.643	0.1536	1.239	-0.413	0.426	0.653	1.236	-0.321	1.255
L231C	0.623	0.1303	1.141	-0.407	0 718	0.625	1.130	-0.274	1.251
L241C	0.640	0.1675	1.294	-0.301	-0.025	0.678	1.275	-0.320	0.991
L251C	0.708	0.1599	1.264	-0.334	0.228	0.705	1.247	-0.295	0.993
L261C	1.003	0.2045	1.430	-0.266	-0.195	0.951	1.476	-0.209	1.138
L271C	1.117	0.1317	1.147	-0.325	-0.209	1.141	1.173	-0.246	0.938

ØM - Mean grain size (phi)
S^2 - Variance
S - Standard deviation
Sk_1 - Skewness
K_1 - Kurtosis
M_z - Graphic mean (phi)
Sort - Inclusive graphic standard deviation
Sk_2 - Inclusive graphic skewness
K_2 - Graphic kurtosis
(Folk, 1968)

Sample Numbers

No alpha suffix - total sample
A and B suffix - terrigenous fraction
C suffix - biogenic fraction

Summary of Textural Statistics for Bulk Sediment Samples and Terrigenous and Biogenic Fractions

APPENDIX C

CALCULATIONS OF PERCENT $CaCO_3$ IN SEDIMENT SAMPLES

		<1.61mm.			>1.61mm.			Total Sample		
	Weight Split	Weight Clastic Fraction	Weight $CaCO_3$ Fraction	Corrected $CaCO_3$ Weight	Weight	Weight Clastic Fraction	Weight $CaCO_3$ Fraction	Total Sample Weight	Total $CaCO_3$ Weight	Total $CaCO_3$ Percent
L111A	101.34	88.73	12.61	93.80	46.80	8.53	38.27	797.93	132.07	16.60
L111B	96.78	84.79	11.99	93.00	46.80	8.53	38.27	797.93	131.27	16.50
L112A	105.70	92.60	13.10	107.00	66.02	12.25	53.77	930.70	160.77	17.25
L121A	92.78	82.16	10.62	87.90	4.64	.18	4.46	773.27	92.36	11.95
L121B	93.54	81.79	11.75	96.40	4.64	.18	4.46	773.27	100.86	13.03
L122A	78.05	68.13	9.92	80.40	5.97	.14	5.83	639.54	86.23	13.50
L122B	81.88	70.75	11.13	86.20	5.97	.14	5.83	639.54	92.03	14.41
L131A	103.70	95.57	8.13	66.30	10.65	.15	10.50	857.70	76.80	8.95
L131B	102.40	94.08	8.32	68.80	10.65	.15	10.50	857.70	79.30	9.25
L132A	104.00	94.34	9.66	80.00	4.42	.08	4.34	865.19	84.34	9.74
L132B										9.69
L141A	109.40	104.36	5.04	41.00	3.71	.50	3.21	893.69	44.21	4.95
L141B	108.90	103.88	5.02	41.10	3.71	.50	3.21	893.69	44.31	4.96
L142A	109.51	104.24	5.27	43.65	3.66	.27	3.39	904.31	47.04	5.21
L142B	116.66	111.73	5.93	46.10	3.66	.27	3.39	904.31	49.49	5.47
L151B	118.49	115.94	2.55	21.17	3.55	.99	2.56	988.16	23.73	2.40
L152A	118.96	116.44	2.52	20.71	4.38	.79	3.59	969.21	24.30	2.51
L152B	117.45	114.88	2.57	21.10	4.38	.79	3.59	969.21	24.69	2.55
L161A	90.03	88.10	1.93	14.19	1.65	.56	1.09	663.33	15.28	2.30
L161B	85.26	83.51	1.75	13.61	1.65	.56	1.09	663.33	14.70	2.22
L162A	111.52	109.14	2.38	18.62	6.28	1.48	4.80	879.43	23.42	2.67
L162B	118.26	115.62	2.64	19.45	6.28	1.48	4.80	879.43	24.25	2.76
L171A	81.79	80.98	0.81	6.32	1.76	.28	1.48	640.20	7.80	1.22
L171B	73.31	72.45	0.86	7.49	1.76	.28	1.48	640.20	8.97	1.40
L172A	76.83	75.37	1.46	12.70	2.89	.15	2.74	671.50	15.44	2.30
L172B	85.74	84.52	1.22	9.52	2.89	.15	2.74	671.50	12.26	1.83
L181A	77.38	76.80	0.58	4.57	0.34	-	-	608.72	4.57	0.75
L181B	83.16	82.50	0.66	4.83	0.34	-	-	608.72	4.83	0.80

		<1.61mm.			>1.61mm.			Total Sample		
	Weight Split	Weight Clastic Fraction	Weight $CaCO_3$ Fraction	Corrected $CaCO_3$ Weight	Weight	Weight Clastic Fraction	Weight $CaCO_3$ Fraction	Total Sample Weight	Total $CaCO_3$ Weight	Total $CaCO_3$ Percent
L182A	76.30	76.02	0.28	2.32	.21	-	-	628.59	2.32	0.37
L182B	76.02	75.48	0.54	4.46	.21	-	-	628.59	4.46	0.71
L191A	70.10	69.47	0.63	5.20	.64	-	-	578.57	5.84	1.01
L191B	66.13	65.59	0.54	4.72	.64	-	-	578.57	5.36	0.93
L192A	68.27	67.98	0.29	2.37	.17	-	-	557.58	2.37	0.43
L192B	71.04	70.70	0.34	2.67	.17	-	-	557.58	2.37	0.48
		<1.41mm.			> 1.41mm.			Total Sample		
L211A	87.05	81.08	5.97	47.20	17.63	5.67	11.96	701.67	59.16	8.44
L211B	79.38	73.65	5.73	49.60	17.63	5.67	11.96	701.67	61.56	8.78
L212A	82.91	76.63	6.28	52.10	20.26	7.03	13.23	706.24	65.33	9.25
L212B	83.41	77.10	6.31	51.95	20.26	7.03	13.23	706.24	65.18	9.23
L221A	72.02	69.92	2.10	17.15	9.15	4.77	4.38	598.15	21.53	3.59
L221B	71.50	69.36	2.14	17.60	9.15	4.77	4.38	598.15	21.98	3.66
L222A	80.40	76.19	4.21	34.50	11.54	3.47	8.07	670.76	42.57	6.35
L222B	79.78	75.62	4.16	34.39	11.54	3.47	8.07	670.76	42.46	6.33
L231A	85.70	81.71	3.99	32.95	10.59	4.01	6.58	717.88	39.53	5.51
L231B	86.00	82.00	4.00	32.90	10.59	4.01	6.58	717.88	39.48	5.51
L232A	68.68	65.99	2.69	22.09	5.44	2.41	3.03	571.72	25.12	4.39
L232B	69.00	66.45	2.55	21.00	5.44	2.41	3.03	571.72	24.03	4.20
L241A	69.42	67.89	1.53	12.60	5.24	2.02	3.22	577.28	15.82	2.74
L241B	69.45	67.96	1.49	12.28	5.24	2.02	3.22	577.28	15.50	2.68
L242A	62.30	61.02	1.28	10.45	3.09	1.39	1.70	513.02	12.15	2.37
L242B	62.32	61.21	1.11	9.06	3.09	1.39	1.70	513.02	10.76	2.10
L251A	76.89	75.27	1.62	13.34	4.60	1.39	3.21	636.85	16.55	2.60
L251B	76.91	75.40	1.51	12.43	4.60	1.39	3.21	636.85	15.64	2.46
L252A	73.83	72.49	1.34	11.04	3.80	1.40	2.40	611.20	13.44	2.20
L252B	73.69	72.30	1.39	11.42	3.80	1.40	2.40	611.20	13.82	2.26
L261A	62.74	62.18	0.56	4.59	2.11	0.69	1.42	517.00	6.01	1.16
L261B	62.30	61.65	0.65	5.37	2.11	0.69	1.42	517.00	6.79	1.31

	<1.41mm.				>1.41mm.			Total Sample		
	Weight Split	Weight Clastic Fraction	Weight $CaCO_3$ Fraction	Corrected $CaCO_3$ Weight	Weight	Weight Clastic Fraction	Weight $CaCO_3$ Fraction	Total Sample Weight	Total $CaCO_3$ Weight	Total $CaCO_3$ Percent
L262A	59.68	59.11	0.57	4.68	3.49	0.80	2.69	493.93	7.37	1.50
L262B	60.30	59.68	0.62	5.04	3.49	0.80	2.69	493.93	7.73	1.57
L271A	85.68	84.87	0.81	6.60	1.45	0.57	0.88	699.86	7.48	1.07
L271B	86.07	84.95	1.12	9.08	1.45	0.57	0.88	699.86	9.96	1.43
L272A	75.40	74.51	0.89	7.62	1.71	0.68	1.03	648.70	8.65	1.33
L272B	78.27	77.24	1.03	8.52	1.71	0.68	1.03	648.70	9.55	1.47
L281A	80.78	79.81	0.97	8.00	2.47	0.70	1.77	668.32	9.77	1.46
L281B	81.58	80.39	1.19	9.71	2.47	0.70	1.77	668.32	11.48	1.72
L282A	69.55	69.08	0.47	3.85	1.99	0.50	1.49	572.04	5.34	0.93
L282B	69.89	69.44	0.45	3.67	1.99	0.50	1.49	572.04	5.16	0.90
L291A	72.91	72.13	0.78	6.45	0.41	0.20	0.21	603.97	6.66	1.10
L291B	73.65	73.10	0.55	4.51	0.41	0.20	0.21	603.97	4.72	0.78
L292A	75.73	75.46	0.27	2.20	0.60	0.32	0.28	618.35	2.48	0.40
L292B	75.80	75.48	0.32	2.61	0.60	0.32	0.28	618.35	2.89	0.47

APPENDIX D

FREQUENCY TABLES FOR BIVALVE SPECIES
LINES L1, L2, AND RL1
(1.65-2.38mm.)

SAMPLES

	L1101	L1102	L1103	L1104	L191	L192	L193	L194	L181	L182	L183	L184	L171	L172	L173	L174	L161	L162	L163	L164	L151	L152	L153	L154	L141	L142	L143	L144	L131	L132	L133	L134	L121	L122	L123	L124	L111	L112	L113	L114
Lucina multilineata	11	14	18	16	12	21	13	19	29	15	24	19	28	27	28	27	64	63	56	36	40	39	23	40	36	37	28	28	26	22	23	18	51	62	58	62	16	12	29	19
Donax variabilis	56	34	59	39	6	13	11	21	8	1	3	8	2	X	X	4	2			X																		1		
Chione intapurpurea					1			1	7	1	7	X	7	6	8	9	38	26	20	17	31	21	21	20	35	20	27	20	6	8	13	16	11	5	3	3	4	4	5	5
Cavilucina trisulcatus					1	2		2	5	1	2	3	5	5	7	10		6	4	5	4	6	1	1	4	3	6	4	2	2	1	3	1	3	3	4	1		3	1
Tellina spp.	23	21	19	14	14	15	19	31	60	18	14	35	42	35	39	60	52	61	44	60	63	43	40	63	49	71	56	62	56	53	60	47	73	73	69	79	13	6	10	6
Venericardia tridentata					2			X	4	3	10	6	12	4	12	10	80	47	30	36	52	44	16	40	51	24	28	30	12	13	20	32	9	10	5	10	36	24	31	19
Ervilia concentrica	134	109	136	112	43	67	44	69	47	15	13	24	18	14	20	27	14	12	7	10	12	6	6	15	3	12	4	5	5	4	5	3	6	7	4	5	6	8	1	1
Strigilla mirabilis	6	6	2	2	4	3	4	8	5	4	4	4	2	X	X	3	X					1								X						1				
Macrocallista nimbosa	14	8	8	8	3	7	3	5	2		2	4	1	2	3	4																								
Scapharca transversa	2		1		1	2	X	2	3	2	4	5	12	4	7	12	38	34	30	25	33	39	15	32	42	37	38	24	33	21	37	32	44	33	29	27	38	46	33	49
Dinocardium robustum		2	1			1			1		2	X			X		2	1	2		2		X				1			1			1							
Lucina radiana			1			2	2	2	6	2	2	3	1	6	1	4	5	3	2	1		3	1	X	1	2	2			3	X		1					1	1	1
Transennella sp.								1			1		2	2	1	3	6	6	8	7	7	6	6	6	16	7	13	7	6	4	9	16	1	4	1	1	2	3	4	6
Arca ovalis	2								2		1		1		1		2	1	1		2	1			1			1				1			1					
Varicorbula operculata					1				1			1	3	3	3	1	30	42	45	42	37	40	36	51	55	53	62	117	119	146	114	98	26	24	32	24	8	10	8	15
Crassinella lunulata									3			2	6	1	4	5	13	8	9	16	13	17	12	17	22	19	15	13	13	6	9	9	7	5	6	7	22	11	24	29
Chione cancellata									1	X				1		1		1	1	X	X																			
Laevicardium pictum					1				2	3		3	5		9	4	11	11	12	8	8	9	7	6	14	10	15	13	17	16	20	12	26	37	43	37	6	1	4	3
Pandora arenosa										X				1			1			1					1		3					3	1	2	4	3		1		
Pandora trilineata		1	1		1		2		3		2			1	2	3	4		1	2	6	2	1		1	1		2		2		1	1			1				
Anomia simplex									2	2	X	6	2		3	2	4	6	4	6	5	9	5	7	6	13	17	8	23	9	12	19	60	56	62	72	11	6	11	12
Chione grus	1			1					1			1	2			3	6	1	3	4	6	4	5	5	3	3	4	10	2	5	4	7	5	9	6	4	31	20	27	31
Abra aequalis									1				1							2			1	2	2	2	X	3	1	2	1	2	1	4	7				
Diplodonta nucleiformis									4				2	1	1		2	3	1	2	1	1	1	2	1	2	1	3	4	X	3	2		3	3	2				
Aequipecten gibbus															1		2	1	X	1	X	1		X	X	1	2	2	2	6	3	2	5	11	11	13	1		2	
Abra nuculoidea											1				1	1										1		1										1		
Corbula swiftiana															1		1	1	X	X	1		2		1		1				X	3		1			20	22	21	16
Gouldia cerina										2							1	1	1	3	X	2	4	X	4	1	3	1	2	2	2	5	1	2	1	2	9	4	5	8
Verticordia ornata													2			1	7	5	3	2	5	5	4	9	9	6	4	2	1	5	1	5	3	4	1	5			1	
Nucula proxima														1			1	1		1	3	X	X	1	1	2	3	1	1		1	X				1	4			1
Nuculana acuta												1												3	1	2			1	1			2	2			1		1	
Macrocallista maculata																				4?	X?		2?		1?	X?	X?	1?	1	X	3	1				1	2		4	1
Glycymeris pectinata																					X			1		1											2		2	1
Divaricella quadrisulcata																							1																	
Lyonsia floridana																							1					3												
Chama congregata																1										1		1										1	2	
Spisula solidissima							1	2			1																										3	1	2	1
Tellina lintea										1	1				2		1	1			2				2		1		X	1			3	2	1					
Corbula sp.																				1						1	1									2		4	1
Lucina amiantus																									1						1					1	2	1	1	3
Montecuta floridana													2		1					1					1	1	1	1		1					1					
Thyasira trisinuata																											1	1											
Erycina floridana																																	1		1	2	1		3
Corbula barrattiana																																				3	1	3	5
Corbula contracta																																							
Arcopsis adamsi																																							
Arca umbonata																																	1	1			1		

X - not present in counted split

Frequency of Bivalve Species (1.65-2.38mm.)
Line L1

SAMPLES

	L2101	L2102	L2103	L2104	L291	L292	L293	L294	L281	L282	L283	L284	L271	L272	L273	L274	L261	L262	L263	L264	L251	L252	L523	L254	L241	L242	L243	L244	L231	L232	L233	L234	L221	L222	L223	L224	L211	L212	L213	L214
Lucina multilineata	8	4	8	11	48	50	30	38	42	58	94	93	62	37	79	60	41	63	51	41	35	48	50	35	44	42	48	34	50	30	28	40	27	27	30	18	8	18	18	13
Donax variabilis	14	9	16	33	8	13	9	17							1	1	1		1																					
Chione intapurpurea					1	1	2	1	10	2	17	11	10	10	13	12	24	20	15	18	19	14	20	21	22	20	15	32	33	26	23	20	29	25	23	23	17	17	14	16
Cavilucina trisulcatus	1		1		4				1	3	2	6	3	6	4	9	5	3	4	4	3	3	8	2	1	3			3	4	2	1		3	2	2	3			2	
Tellina spp.	6	5	8	9	19	43	24	27	41	38	75	51	38	34	65	50	34	46	34	26	53	37	46	56	44	30	41	31	60	30	29	39	31	27	53	39	37	32	46	30
Venericardia tridentata	1				4	3	2	4	21	23	31	26	19	16	32	27	52	43	66	29	49	40	45	61	43	30	34	40	37	39	49	46	25	37	30	35	21	18	20	29
Ervilia concentrica	38	27	38	87	25	47	27	46	17	20	33	19	19	18	33	23	14	16	10	9	8	4	4	7	2	2	5		4	6	1	2	3	1	1		2	6	2	1
Strigilla mirabilis	4	3	2	3	2	5		2					2			1								1																
Macrocallista nimbosa	3	5	3	8	5	3	3	5	4		2	2	1		1		1	2					1																	
Scapharca transversa			1	1	2	3	1		8	10	16	12	9	11	18	17	26	27	34	33	40	43	32	29	44	37	36	43	55	52	45	39	47	46	60	49	33	57	52	60
Dinocardium robustum			1			1	1		2	1			1	1	1	1	2	1						2		1	1			1	1							1		
Lucina radians					4	2	3	2	3	8	9	7	4	2	10	6	2	4	5	2	3	2	2	2	3			4		1	1	2	1		1					
Transennella sp.									1	4	3	1	2	2	3	5	4	4	6	8	5	6	10	4	6	7	4	13	11	3	7	9	8	5	5	7	6	6	1	5
Arca ovalis					2				3	2	2		1		1		1	2		1		1	1			1		2												
Varicorbula operculata									7	4	8	5	5	4	4	3	30	20	33	19	39	39	46	46	39	37	58	50	54	47	49	56	52	50	43	44	51	80	67	49
Crassinella lunulata						1			3	7	10	10	12	7	8	7	7	12	17	11	7	26	20	23	17	19	15	14	19	17	15	15	26	23	20	18	31	31	44	26
Chione cancellata					1	1			1			1						1												1					1					
Laevicardium pictum			1				2	1	5	11	9	8	4	4	11	7	17	12	18	19	16	13	15	16	26	19	23	12	23	15	11	10	9	13	15	15	5	10	10	7
Pandora arenosa											1			1			2	5		2	1			1		1	1	1	1		1	3	1	1			2	3	1	2
Pandora trilineata							1		3			1					2	1			1	1	1		1		2			3		1			2		1	2	1
Anomia simplex					3	1		2	2		5	8	7	3	5	3	5	2	2	4	6	5	2	4	5	5	16	4	12	11	7	11	8	14	7	7	5	12	9	8
Chione gruss										3	4			3	1		5	5	3	1	1	6	5	3	5	3	6	5	14	14	6	10	12	16	9	13	23	16	24	26
Abra aequalis												1	1	1									1		1		2	2	1	2			1	2	2				2
Diplodonta nucleiformis										1	1	1	1	1		1	1	1		2	2		1	1		1	3	1	1		1	2	1	1	1	1	1	2		
Aequipecten gibbus								1	1		3	2				2		1		1	4	2	1	1	1	2	4	2	1	1	3	3	6	1	5	3	2	2	3	2
Abra nuculoidea																					1					1		1							1				1	
Crobula swiftiana									1		2		1		2			6	2	2	2	1	1	5	3		4	1	1	4	5	4	2	5		1	2	5	5	2
Gouldia cerina												1	1		1	2		2	3	1	3	4	2	5	3	4	3	9	10	4	8	8	12	8	7	10	17	16	10	10
Verticordia ornata										2	4	1	1	1	6	4	4	8	2	4	2	1	3	6	7	1	5	4	2	3	3	4	4	7	4	2	4	8	2	2
Nucula proxima																	1				2	2	1	2	1	2	1			1		2	2		2	2	1	5	6	6
Nuculana acuta												1	1		1	1	1	2	1	1	1	5	4	5	5	2	2		5	3			1	2	5	2	1		3	
Macrocallista maculata																	1	1?			1	1	1	2	2	2	2	1	3	1	2	3			4	1	2	3		3
Glycymeris pectinata																																								
Divaricella quadrisulcata																																								
Lyonsia floridana																																								
Chama congregata																					1																			
Spisula solidissima					1			1																																
Tellina lintea					1		1				2		1		1	1		1	2	1	2	2	1	1	1	1	1	1	1		1	2			1			2		
Corbula sp.																																								
Lucina amiantus																				1																				
Montecuta floridana						1		1					1	1		1			1							1														2
Thyasira trisinuata																					1	1		1							1			1	1			1	
Erycina floridana																					1				5	1	3	1	1			3		2	3		1	4	2	1
Corbula barrattiana																																								
Corbula contracta																																								
Arcopsis adamsi																																								
Arca umbonata																																								

Frequency of Bivalve Species (1.65-2.38mm.)
Line L2

SAMPLES

	RL161	RL162	RL151	RL152	RL141	RL142	RL131	RL132	RL121	RL122	RL111	RL112	RL171	RL172	RL181	RL182	RL191	RL192	RL1101	RL1102	RL1111	RL1112
Lucina multilineata	54	43	41	55	63	43	58	52	48	46	67	42	57	44	71	85	69	94	72	68	93	69
Donax variabilis																						
Chione intapurpurea	9	4	5	8	7	1	3	5			4		2	3	4	2	3	5	5	3	7	6
Cavilucina trisulcatus	2	3	1	2	6	2	2	1	2	1	2		1		2	2		3		2	5	3
Tellina spp.	76	78	67	75	83	60	68	68	45	52	24	34	30	33	30	32	30	23	27	20	26	16
Venericardia tridentata	16	6	9	11	11	5	5	6	9	3	13	9	4	3	11	12	10	20	15	16	16	14
Ervilia concentrica	4	9	4	5	6	4	6	4	3	1	4	2	2	2	2	2	3	1	4	2	6	5
Strigilla mirabilis																						
Macrocallista nimbosa																						
Scapharca transversa	37	37	32	24	22	18	29	36	24	24	35	45	24	19	52	37	42	42	58	41	68	47
Dinocardium robustum	1	2				1							1	1	1		1				2	3
Lucina radians		1	1				1			2	1		1			1				1	1	1
Transennella sp.	5	3	1	2	2	2		3	1	1	8	3	2	3	3	4	3	1	2	1	3	3
Arca ovalis																					1	1
Varicorbula operculata	41	34	26	24	19	16	25	25	16	19	26	25	30	20	36	23	29	43	26	28	33	28
Crassinella lunulata	11	10	2	3	4	3	7	5	5	6	8	11	3	5	9	10	17	13	18	10	16	20
Chione cancellata					1										3		1		2		5	7
Laevicardium pictum	33	30	56	47	38	37	50	47	38	42	18	10	36	32	29	31	12	19	12	12	9	9
Pandora arenosa	3		2	2	3	2	6			1			1	6	2	1	3			2	1	
Pandora trilineata										1								1	2			
Anomia simplex	39	35	64	59	57	46	68	61	99	105	46	24	101	95	67	80	31	54	67	52	49	38
Chione grus	2	1	4	5	3	2	8	3	21	9	46	47	21	6	11	11	19	13	23	14	22	24
Abra aequalis	4	2	2	2	2	2	2		1	1		3	3	1	4	5			3		2	2
Diplodonta nucleiformis	2	2	4	2	5	2	3		1		1		1		2	3	1	3		3		1
Aequipecten gibbus	3	5	11	6	7	12	6	12	10	13	3	2	10	11	10	5	6	2	4	4	4	4
Abra nuculoides	1				1									2	1					1	3	3
Corbula swiftiana					1						7	3	3	1	3	4	2	2	9	4	6	14
Gouldia cerina	1	1	1	2	1	1	1	4	1	2	7	11	3	3	5	7	6	5	11	6	7	14
Verticordia ornata	3	2	1	1	3	1		5		2	3	2				3		1		3	2	2
Nucula proxima									2	1	1			1	1		1	1	1		1	
Nuculana acuta	1	2		2	3		2	1			9	4	4	3	10	6	10	13	12	18	20	15
Macrocallista maculata							1				1	1		1			1					
Glycymeris pectinata																1				2		2
Divaricella quadrisulcata																						
Lyonsia floridana																						
Chama congregata								1	3		3	4	3	2		1		2		1		3
Spisula solidissima																						
Tellina lintea	1		1	2			1	1	1	1		1			1	3	2					
Corbula sp.															1						1	1
Lucina amiantus											3	1		1	3	4	1	3	7	6	11	13
Montecuta floridana							1														1	
Thyasira trisinuata			1					1	1	1			1	3	1	2	1	1	1		1	
Erycina floridana																						
Corbula barrattiana																						
Corbula contracta							2															
Arcopsis adamsi					1		1															
Arca umbonata																						

Frequency of Bivalve Species (1.65-2.38mm.)
Line RL1

APPENDIX E

RELATIVE FREQUENCY TABLES FOR MAJOR BIOGENIC GRAIN TYPES (>2.38mm.) SEMIQUANTITATIVE SAMPLES LINES L1, L2, AND RL1

SAMPLES

BIOGENIC GRAIN TYPE	L111	L112	L113	L114	L121	L122	L123	L124	L131	L132	L133	L134	L141	L142	L143	L144	L151	L152	L153	L154	L161	L162	L163	L164	L171	L172	L173	L174	L181	L182	L183	L184	L191	L192	L193	L194	L2101	L2102	L2103	L2104
Bivalves (unbroken + broken)	9.4	9.7	9.8	8.4	17.6	21.4	30.3	25.5	25.7	21.9	27.4	24.5	23.7	21.8	23.8	26.2	20.2	26.3	21.8	20.5	19.1	22.5	18.5	21.3	19.1	27.4	22.9	23.4	15.2	21.0	27.2	21.9	29.7	24.2	25.8	23.6	32.8	40.0	38.2	31.6
Bivalve Fragments	45.3	38.8	39.3	39.5	17.1	25.1	14.7	17.6	25.5	21.0	25.5	25.4	43.2	29.5	35.9	33.4	47.7	41.3	43.1	39.1	44.1	44.0	38.4	39.0	21.9	28.5	28.8	28.7	13.8	24.2	32.8	24.3	20.0	22.1	15.4	16.6	22.8	23.1	21.5	26.4
Gastropods and Gastropod Fragments	17.0	13.6	18.8	19.1	4.1	4.2	3.7	2.9	3.8	3.0	6.0	4.0	7.1	5.6	5.9	4.2	6.1	6.7	7.2	7.8	8.3	8.3	8.3	7.9	7.6	8.3	8.6	6.9	6.5	11.6	13.0	10.2	15.7	15.6	12.5	14.8	8.0	10.6	8.3	14.4
Plagiobrissus grandis Fragments	0.5	1.5	0.4	1.2	12.3	11.1	10.6	11.5	10.2	17.6	8.1	9.0	1.6	15.4	6.6	13.6	5.6	4.7	6.9	8.5	13.1	4.7	7.1	5.8	18.7	5.9	3.6	6.5	21.7	6.2	4.6	7.4	3.0	3.8	4.4	9.9	3.6	2.5	0.9	3.5
Encope spp. Fragments	5.9	7.9	4.3	3.5	16.6	14.3	18.4	16.4	15.1	16.6	15.2	16.0	11.3	16.2	15.7	14.6	12.8	15.4	14.6	16.3	11.6	14.0	21.6	21.2	25.9	23.0	30.5	30.5	39.5	32.0	17.8	30.6	33.0	33.4	37.3	30.9	32.0	21.3	28.0	19.6
Coralline Algae	12.7	18.1	15.2	18.3	24.6	12.4	10.7	12.8	7.6	9.0	8.2	11.2	4.4	4.4	5.1	2.8	1.4	1.0	1.4	1.1	0.2	0.6	0.2	0.3	-	0.2	0.1	-	-	-	0.2	-	-	-	-	-	-	-	-	-
Bryozoan Zoaria	0.2	0.2	0.4	0.2	1.2	0.8	1.6	1.3	1.0	1.1	1.3	1.2	1.0	0.6	0.6	0.2	0.2	0.1	0.1	0.1	-	-	-	0.1	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-
Opercula	5.6	5.4	7.8	5.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barnacle Fragments	3.1	5.0	3.9	4.4	4.6	4.9	3.6	4.0	4.9	3.5	4.6	5.0	3.9	3.6	3.5	2.8	2.8	2.1	2.4	3.8	2.1	2.4	2.8	2.1	1.8	3.5	2.3	2.4	3.3	1.3	0.5	2.4	1.3	1.8	1.2	1.6	0.4	0.6	0.5	2.3
Crustacean Fragments	0.5	-	0.4	-	1.6	2.3	3.8	4.5	4.4	3.5	2.7	1.8	2.4	1.5	1.7	1.4	1.8	1.5	2.4	1.1	1.4	2.7	2.5	1.3	3.8	1.6	1.7	1.2	1.0	3.0	3.6	1.3	3.0	3.0	2.4	1.8	0.4	1.9	2.6	2.3
Foraminiferida	-	-	-	-	2.3	3.5	2.7	3.6	1.9	1.2	1.0	1.6	1.6	1.5	1.2	0.7	1.5	1.0	-	1.6	0.2	0.6	0.6	1.3	1.4	1.7	1.5	0.6	0.2	0.8	0.2	2.0	0.3	-	0.2	0.3	-	-	-	-

BIOGENIC GRAIN TYPE	L211	L212	L213	L214	L221	L222	L223	L224	L231	L232	L233	L234	L241	L242	L243	L244	L251	L252	L253	L254	L261	L262	L263	L264	L271	L272	L273	L274	L281	L282	L283	L284	L291	L292	L293	L294	L2101	L2102	L2103	L2104
Bivalves (unbroken + broken)	9.4	13.5	16.1	12.7	15.2	14.5	15.2	13.7	17.2	14.0	16.3	15.4	22.7	21.3	19.8	21.4	23.0	21.5	23.0	23.8	22.3	24.9	28.0	22.3	25.8	21.6	26.0	27.4	26.2	22.7	23.1	21.6	22.6	22.7	24.2	27.7	11.1	26.4	31.0	20.4
Bivalve Fragments	49.2	43.7	34.1	45.1	45.5	53.5	45.6	51.3	48.9	46.8	47.2	44.3	37.9	37.7	37.2	41.0	39.3	43.9	37.3	36.5	30.7	34.8	34.9	40.0	31.7	39.5	31.3	34.7	35.7	29.3	31.6	29.5	18.5	16.5	13.7	18.5	20.0	24.5	17.8	11.1
Gastropods and Gastropod Fragments	9.1	8.7	6.9	8.2	6.7	10.4	8.2	7.5	10.0	7.9	11.5	7.6	5.6	7.4	7.5	6.9	5.6	6.7	7.1	5.7	6.2	7.5	6.9	7.9	6.9	9.1	5.5	9.5	5.0	9.7	7.3	7.5	10.8	10.1	9.3	10.0	8.9	9.4	2.2	7.4
Plagiobrissus grandis Fragments	1.9	1.0	1.7	1.3	2.3	1.7	1.3	3.3	3.2	1.8	4.1	4.6	4.9	6.0	6.0	4.1	6.3	4.1	8.8	5.1	4.1	4.0	3.9	4.1	9.4	2.7	7.9	3.5	4.3	4.8	7.4	12.4	3.6	3.7	5.1	3.6	2.2	-	-	6.5
Encope spp. Fragments	4.6	7.3	7.7	4.6	11.0	6.6	9.5	6.8	11.7	14.4	10.9	14.7	20.4	16.0	21.5	16.6	17.8	17.2	18.0	20.1	27.8	20.2	20.5	20.5	18.9	20.9	22.7	18.6	21.0	28.0	22.6	19.7	39.8	42.8	44.2	36.9	57.8	37.7	46.8	47.3
Coralline Algae	17.9	18.2	25.4	22.8	11.4	9.4	11.1	9.3	3.7	6.6	3.9	6.1	1.7	2.5	0.9	3.0	1.0	1.2	1.8	1.1	1.1	-	0.4	0.4	-	-	-	-	0.2	-	-	0.1	-	-	-	-	-	-	-	-
Bryozoan Zoaria	1.0	0.8	1.4	0.9	0.8	1.3	0.9	1.0	0.5	1.2	3.9	0.6	0.7	0.2	0.2	0.5	0.3	0.1	0.2	0.2	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Opercula	3.5	2.5	1.7	2.2	2.3	2.5	2.7	2.3	0.6	0.4	0.4	0.2	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barnacle Fragments	2.3	3.8	3.6	1.7	2.5	-	2.7	3.0	2.3	3.4	0.5	3.7	3.1	4.3	3.7	2.8	2.3	2.2	0.6	3.1	2.0	2.3	2.2	1.2	1.5	2.3	1.9	1.3	2.1	1.9	2.5	2.9	1.1	1.2	1.2	0.8	-	-	-	-
Crustacean Fragments	1.2	0.4	1.1	0.4	2.0	-	2.7	1.9	1.5	2.7	3.9	2.6	1.8	2.5	2.6	2.3	3.1	2.3	2.0	2.6	4.3	4.6	2.4	2.4	4.2	1.9	3.2	2.9	2.9	1.9	2.6	3.9	3.4	2.4	1.2	1.7	-	1.9	2.2	7.4
Foraminiferida	-	-	0.4	0.2	0.2	-	-	-	0.6	1.1	1.4	0.4	1.2	2.1	0.4	1.5	1.4	0.9	1.0	2.0	1.4	1.7	0.8	1.2	1.5	2.1	1.5	2.2	2.6	1.7	3.0	2.4	0.2	0.7	1.2	0.8	-	-	-	-

Relative Frequency of Biogenic Grain Types (>2.38mm.)
Lines L1 and L2

BIOGENIC GRAIN TYPE	SAMPLES																					
	RL111	RL112	RL121	RL122	RL131	RL132	RL141	RL142	RL151	RL152	RL161	RL162	RL171	RL172	RL181	RL182	RL191	RL192	RL1101	RL1102	RL1111	RL1112
Bivalves (unbroken + broken)	12.3	18.8	27.0	25.4	22.7	28.6	26.7	26.1	19.4	25.4	20.7	20.6	17.9	21.2	17.2	14.4	14.6	14.3	13.9	12.7	12.2	11.9
Bivalve Fragments	13.1	15.5	19.9	20.2	16.2	17.4	19.5	16.9	21.0	17.4	23.8	20.3	22.3	17.4	20.4	25.6	24.7	22.1	26.8	24.8	25.9	31.8
Gastropods and Gastropod Fragments	8.4	7.7	4.1	4.5	3.2	4.4	4.0	3.6	3.2	3.8	4.3	6.9	11.1	4.1	8.3	13.8	11.6	9.5	8.2	10.5	15.3	13.8
Plagiobrissus grandis Fragments	9.9	8.3	20.9	18.1	19.9	17.2	14.1	19.2	13.3	13.2	13.0	9.2	11.0	24.5	5.4	7.5	3.8	5.5	3.8	2.9	1.7	1.7
Encope spp. Fragments	15.9	11.6	11.5	15.7	15.8	11.6	13.0	14.6	13.7	13.6	11.9	13.0	12.1	13.0	10.5	11.0	8.9	9.0	8.5	5.2	4.9	5.8
Coralline Algae	31.6	32.8	6.8	8.4	12.0	11.5	10.7	11.6	17.6	12.3	12.6	18.2	16.1	11.1	30.4	18.4	27.5	28.3	28.2	32.7	30.8	24.1
Bryozoan Zoaria	2.0	1.3	0.7	0.4	1.1	0.6	1.5	0.2	0.6	1.4	1.1	0.8	0.3	0.3	0.8	0.5	0.7	0.6	0.5	0.4	0.2	0.3
Opercula	0.4	0.8	-	-	-	-	-	-	-	-	-	-	5.9	1.6	3.0	5.5	3.8	5.6	5.4	4.5	2.9	5.1
Barnacle Fragments	4.9	1.8	4.6	2.1	3.5	3.9	4.0	2.7	4.3	4.4	4.7	3.6	1.7	2.6	2.5	2.4	3.4	3.7	3.5	4.7	4.6	4.3
Crustacean Fragments	1.0	1.5	2.1	2.3	3.1	2.6	2.4	2.5	4.7	4.8	3.6	5.4	1.1	3.6	0.5	0.9	0.4	1.2	1.0	1.2	1.0	0.8
Peneroplids	0.4	-	2.3	2.9	2.6	2.3	4.0	2.9	2.1	3.6	4.5	2.1	0.6	0.7	1.2	-	0.6	0.4	0.2	0.5	0.2	0.3

Relative Frequency of Biogenic Grain Types (>2.38mm.)
Line RL1

APPENDIX F

2 BY 2 CONTINGENCY TABLES OF BIVALVE SPECIES OCCURRENCES AT LOCATIONS ON LINES L1, L2, AND RL1

SPECIES

SPECIES		(2)		(7)		(9)		(10)		(11)		(12)		(13)		(17)		(24)		(26)		(28)		(29)		(32)		(33)		(37)		(38)		(39)		(42)		(45)		(46)		(47)		(48)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(1)	P	12	1	20	0	11	0	14	0	27	4	21	1	8	0	14	0	23	0	23	3	27	3	27	3	23	2	15	0	12	1	26	0	26	0	26	0	12	0	25	4	19	0	27	1
	A	15	3	7	4	16	4	13	4	0	0	6	3	19	4	13	4	4	4	4	1	0	1	0	1	4	2	12	4	15	3	1	4	1	4	1	4	15	4	2	0	8	4	0	3
(2)	P			9	11	6	5	5	9	12	17	9	13	6	2	6	7	11	12	11	14	12	18	12	17	12	13	7	8	10	3	12	14	12	14	10	14	5	7	11	17	9	10	12	16
	A			4	7	7	13	8	9	1	1	4	5	7	16	7	11	2	6	2	4	1	0	1	1	1	5	6	10	3	15	1	4	1	4	3	4	8	11	2	1	4	8	1	2
(7)	P					9	2	12	2	20	11	16	5	7	1	11	1	18	5	16	10	20	10	20	11	18	8	12	3	10	3	19	7	19	7	19	7	11	1	19	11	14	5	20	8
	A					11	9	8	9	0	0	4	6	13	10	9	10	2	6	4	1	0	1	0	0	2	3	8	8	10	8	1	4	1	4	1	4	9	10	1	0	6	6	0	3
(9)	P							8	6	11	19	8	14	2	6	7	6	11	12	9	17	11	19	11	19	10	15	10	5	8	5	11	15	11	15	11	15	9	2	11	19	10	9	11	17
	A							3	14	0	1	3	6	9	14	4	14	0	8	2	3	0	1	0	1	1	5	1	15	3	15	0	5	0	5	0	5	2	18	0	1	1	11	0	3
(10)	P									14	16	11	11	5	3	9	4	12	11	11	15	14	16	13	16	12	15	9	6	6	7	14	12	14	12	14	12	10	2	14	16	13	7	14	14
	A									0	1	3	6	9	14	5	13	2	6	3	2	0	1	1	1	2	4	5	11	8	10	0	5	0	5	0	5	4	15	0	1	1	10	0	3
(11)	P											22	0	8	0	13	0	23	0	25	1	30	0	29	1	25	0	15	0	13	0	26	0	26	0	26	0	12	0	28	1	19	0	28	0
	A											8	1	22	1	17	1	7	1	5	0	0	1	1	0	5	1	15	1	17	1	4	1	4	1	4	1	18	1	2	0	11	1	2	1
(12)	P													6	2	9	4	17	6	22	8	22	8	22	8	20	7	7	6	9	4	10	6	10	6	10	6	8	4	11	9	13	6	22	6
	A													16	7	13	5	5	3	0	1	0	1	0	1	2	2	15	3	13	5	12	3	12	3	12	3	14	5	11	1	9	3	0	3
(13)	P															5	8	7	16	7	19	8	22	8	22	8	17	5	10	6	7	8	18	8	18	8	18	5	7	8	21	6	13	8	20
	A															3	15	1	7	1	4	0	1	0	1	0	6	3	13	2	16	0	5	0	5	0	5	3	16	0	2	2	10	0	3
(17)	P																	13	10	10	16	13	17	13	17	12	14	10	5	8	5	13	13	13	13	13	13	10	2	13	16	10	9	13	15
	A																	0	8	3	2	0	1	0	1	1	4	3	13	5	13	0	5	0	5	0	5	3	16	0	2	3	9	0	3
(24)	P																			20	6	23	7	23	7	21	4	15	0	13	0	23	3	23	3	23	3	12	0	21	8	12	2	23	5
	A																			3	2	0	1	0	1	2	4	8	8	10	8	0	5	0	5	0	5	11	8	2	0	11	6	0	3
(26)	P																					25	5	26	4	23	2	14	1	13	0	22	4	22	4	22	4	10	2	26	5	16	3	24	4
	A																					1	0	0	1	3	3	12	4	13	5	4	1	4	1	4	1	16	3	0	0	10	2	2	1

SPECIES

SPECIES		(51)		(53)		(56)		(57)		(58)		(59)		(62)		(65)		(67)		(71)		(72)		(73)		(74)		(76)		(78)		(83)		(84)		(97)		(98)		(100)		(101)		(103)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(1)	P	11	4	23	2	26	3	18	0	15	0	26	0	12	0	23	0	27	4	17	0	27	4	20	0	11	0	27	4	27	3	22	0	8	4	23	0	22	0	27	2	26	3	27	2
	A	16	0	4	2	1	1	9	4	12	4	1	4	15	4	4	4	0	0	10	4	0	0	7	4	16	4	0	0	0	1	5	4	19	0	4	4	5	4	0	2	1	1	0	2
(2)	P	7	8	12	13	12	17	10	8	8	7	12	13	7	5	10	13	13	18	9	8	13	18	10	10	7	4	13	18	13	17	11	12	5	7	12	11	11	11	12	17	12	17	12	17
	A	6	10	1	5	1	1	3	10	5	11	1	5	6	13	3	5	0	0	4	10	0	0	3	8	6	14	0	0	0	1	2	6	8	11	1	7	2	7	1	1	1	1	1	1
(7)	P	8	7	16	9	20	10	14	4	7	6	8	4	18	8	15	8	20	11	14	3	20	11	15	5	8	3	20	11	20	10	14	9	7	6	17	6	16	6	20	9	20	10	20	9
	A	12	4	4	2	0	1	6	7	13	5	12	7	2	3	5	3	0	0	6	8	0	0	5	6	12	8	0	0	0	1	6	2	13	5	3	5	4	5	0	2	0	1	0	2
(9)	P	4	11	11	14	11	19	10	8	6	10	11	15	9	3	11	13	11	20	9	8	11	20	10	10	7	4	11	20	11	19	10	13	1	11	10	13	11	11	11	18	11	20	11	18
	A	7	9	0	6	0	1	1	12	5	10	0	5	2	17	0	7	0	0	2	12	0	0	1	10	4	10	0	0	0	1	1	7	10	9	1	7	0	9	0	2	0	0	0	2
(10)	P	4	11	13	12	13	16	12	6	7	8	14	12	7	5	14	10	14	17	9	8	14	17	11	9	6	5	14	17	14	16	12	11	3	9	11	12	12	10	14	15	14	16	14	15
	A	10	16	1	5	1	1	2	11	7	9	0	5	7	12	0	7	0	0	5	9	0	0	3	8	8	12	0	0	0	1	2	6	11	8	3	5	2	7	0	2	0	1	0	2
(11)	P	14	1	24	1	28	1	18	0	15	0	26	0	12	10	23	0	30	1	17	0	30	1	20	0	11	0	30	1	29	1	23	0	11	1	23	0	22	0	29	0	28	1	29	0
	A	16	0	6	0	2	0	12	1	15	1	4	1	18	1	7	1	0	0	13	1	0	0	10	1	19	1	0	0	1	0	7	1	19	0	7	1	8	1	1	1	2	0	1	1
(12)	P	10	5	17	8	22	7	12	6	12	3	10	6	7	5	17	6	22	9	13	5	22	9	14	6	7	4	22	9	22	8	18	5	8	4	18	5	12	6	22	7	22	7	22	7
	A	12	4	5	1	0	2	10	3	10	6	12	3	15	4	5	3	0	0	9	4	0	0	8	3	15	5	0	0	0	1	4	4	14	5	4	4	10	3	0	2	0	2	0	2
(13)	P	2	13	7	18	7	21	6	12	4	11	8	18	3	9	6	17	8	23	7	10	8	23	6	14	3	9	8	23	8	22	6	17	2	10	7	15	6	16	8	21	7	21	8	21
	A	6	10	1	5	1	2	2	11	4	12	0	5	5	14	2	6	0	0	1	13	0	0	2	9	5	14	0	0	0	1	2	6	6	13	1	8	2	7	0	2	1	2	0	2
(17)	P	11	2	12	13	12	16	10	8	6	9	13	13	6	6	13	10	13	18	9	8	13	18	12	8	5	6	13	18	13	17	10	13	2	10	11	12	12	10	13	16	12	16	13	16
	A	2	16	1	5	1	2	3	10	7	9	0	5	7	12	0	8	0	0	4	10	0	0	1	10	8	12	0	0	0	1	3	5	11	8	2	6	1	8	0	2	1	2	0	2
(24)	P	8	7	21	4	22	6	17	7	13	6	23	3	12	0	21	2	23	8	15	2	23	8	18	2	9	2	23	8	23	7	19	3	2	8	16	2	22	1	23	6	22	6	23	6
	A	15	1	2	4	1	2	6	1	10	2	0	5	11	8	2	6	0	0	8	6	0	0	5	6	14	6	0	0	0	1	4	5	21	0	7	6	1	7	0	2	1	2	0	2
(26)	P	14	1	23	2	25	4	15	3	13	2	22	4	12	0	20	3	26	5	15	2	26	5	17	3	9	2	16	3	26	4	20	3	11	2	20	3	19	3	25	4	25	3	25	3
	A	12	4	3	3	1	2	11	2	13	3	4	2	14	5	6	2	0	0	11	3	0	0	9	2	17	3	10	2	0	1	6	2	15	3	6	2	7	2	1	1	1	2	1	2

2 by 2 Contingency Tables for Bivalve Species Pairs
Occurrences at Locations on Lines L1, L2, and RL1
P = Present A = Absent

SPECIES

SPECIES		(104)		(105)		(111)		(115)		(116)		(121)		(124)		(125)		(126)		(127)		(128)		(129)		(135)		(138)		(140)		(143)		(146)		(147)		(154)		(156)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(1)	P	16	0	12	0	23	0	27	3	24	0	12	0	25	4	26	2	26	4	11	0	9	0	8	2	16	4	15	0	23	1	19	1	27	4	21	1	27	3	24	1
	A	11	4	15	4	4	4	0	1	3	4	15	4	2	0	1	2	1	0	16	4	18	4	19	2	11	0	12	4	4	3	8	3	0	0	6	3	0	1	3	3
(2)	P	9	7	6	6	11	12	13	17	10	14	7	5	12	16	12	16	12	18	2	9	6	3	7	3	8	12	8	7	10	14	9	11	13	18	9	13	13	17	11	14
	A	4	11	7	12	2	6	0	1	3	4	6	13	1	2	1	2	1	0	11	9	7	15	6	15	5	6	5	11	3	4	4	7	0	0	4	5	0	1	2	4
(7)	P	12	4	9	3	18	5	20	10	18	6	8	3	20	11	20	9	10	10	8	3	7	2	6	4	10	10	13	2	16	8	17	3	17	4	9	7	20	10	17	8
	A	8	7	11	8	2	6	0	1	2	5	12	8	0	0	0	2	10	1	12	8	13	9	14	7	10	1	7	9	4	3	3	8	3	7	11	4	0	1	3	3
(9)	P	9	7	8	4	11	12	11	19	11	13	4	8	11	18	11	17	11	19	4	7	7	2	6	4	5	15	10	5	10	10	8	16	11	20	11	11	11	19	10	15
	A	2	13	3	16	0	8	0	1	0	7	7	12	0	2	0	3	0	1	7	13	4	18	5	16	6	5	1	15	1	10	3	4	0	0	0	9	0	1	1	5
(10)	P	8	8	8	4	13	10	14	16	14	10	14	15	14	14	6	6	14	16	7	4	5	4	4	6	8	12	7	6	4	11	13	7	14	17	12	7	14	16	4	12
	A	6	9	3	13	1	7	0	1	0	7	0	2	0	3	8	11	0	1	7	13	9	13	10	11	6	5	7	11	10	6	1	10	0	0	2	10	0	1	10	5
(11)	P	16	0	12	0	23	0	29	1	24	0	12	0	27	1	28	0	29	1	11	0	9	0	9	1	19	1	15	0	24	0	20	0	30	1	22	0	29	1	25	0
	A	14	1	18	1	7	1	1	0	6	1	18	1	3	0	2	1	1	0	19	1	21	1	21	0	11	0	15	1	6	1	10	1	0	0	8	1	1	0	5	1
(12)	P	11	5	7	5	18	6	22	8	18	6	10	2	12	7	11	6	22	8	10	1	6	3	6	4	16	4	10	5	17	7	15	5	22	9	15	7	22	8	18	7
	A	11	4	15	4	4	3	0	1	4	3	12	7	8	2	10	3	0	1	12	8	16	6	16	5	6	5	12	4	5	2	7	4	0	0	5	2	0	1	4	2
(13)	P	5	11	6	7	7	16	8	22	6	18	4	8	8	20	8	20	8	23	3	7	3	6	1	9	5	15	6	9	7	17	7	13	8	23	6	16	8	22	7	18
	A	3	12	3	16	1	7	0	1	2	5	4	15	0	3	0	3	0	0	5	16	5	17	7	13	3	8	2	14	1	6	1	10	0	0	2	7	0	1	1	5
(17)	P	9	7	7	13	12	11	13	17	11	13	4	8	13	16	13	15	13	16	8	3	5	14	4	6	5	16	11	4	11	11	12	8	13	18	12	10	13	17	12	13
	A	4	11	6	5	1	7	0	1	2	5	9	10	0	2	0	3	0	2	5	15	8	4	9	12	8	2	2	14	2	7	1	10	0	0	1	3	0	1	1	5
(24)	P	16	0	12	0	22	7	23	7	22	3	11	1	23	7	23	5	23	7	9	2	9	0	7	3	12	8	15	0	20	4	12	2	23	8	20	2	23	7	21	4
	A	7	8	11	8	1	1	0	1	1	5	12	7	0	1	0	3	0	1	14	6	14	8	16	5	11	0	8	8	3	4	5	6	0	0	3	5	0	1	2	4
(26)	P	15	1	11	1	19	4	26	4	15	3	11	2	24	4	24	4	25	5	8	3	7	2	9	1	17	3	13	2	21	3	17	3	26	5	19	3	26	4	21	4
	A	11	4	15	4	7	1	0	1	11	2	15	3	2	1	2	1	1	0	18	2	19	3	17	4	9	2	13	3	5	2	9	2	0	0	7	2	0	1	5	1

SPECIES		(29)		(32)		(33)		(37)		(38)		(39)		(42)		(45)		(46)		(47)		(48)		(51)		(53)		(56)		(57)		(58)		(59)		(62)		(65)		(67)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(28)	P	29	1	25	0	15	0	13	0	26	0	26	0	26	0	12	0	29	1	19	0	28	0	14	1	24	1	29	1	18	0	16	0	26	0	12	0	23	0	26	1
	A	1	0	5	1	15	1	17	1	4	1	0	1	0	1	18	1	1	0	11	1	2	1	16	0	6	0	1	0	12	1	14	1	0	1	18	1	3	1	0	0
(29)	P			25	0	15	0	13	0	26	0	26	0	26	0	12	0	28	1	19	0	28	0	14	1	25	0	29	0	18	0	15	0	26	0	12	0	23	0	30	1
	A			5	1	15	1	17	1	4	1	4	1	4	1	18	1	2	0	11	1	2	1	16	0	5	1	1	1	12	1	15	1	4	1	18	1	7	1	0	0
(32)	P					14	1	13	0	23	3	23	3	23	3	11	1	24	6	17	5	25	4	11	4	23	3	24	5	17	5	14	0	23	3	12	0	20	3	25	6
	A					11	5	12	6	2	3	2	3	2	3	14	5	1	0	8	1	0	2	14	2	2	3	1	1	7	1	11	1	2	3	13	6	5	3	0	0
(33)	P							11	2	15	11	15	11	15	11	11	1	13	16	14	5	15	13	4	11	15	10	14	15	14	4	7	9	15	11	11	1	15	8	15	6
	A							4	14	0	5	0	5	0	5	4	15	2	0	1	11	0	3	11	5	0	6	1	1	1	12	8	7	0	5	4	15	0	8	0	0
(37)	P									13	13	13	13	13	13	8	4	12	18	11	8	13	15	5	10	13	12	12	17	10	8	6	8	13	13	10	2	12	11	13	18
	A									0	5	0	5	0	5	5	14	1	0	2	10	0	3	8	8	0	6	1	1	3	10	7	10	0	5	3	16	1	7	0	0
(38)	P											26	0	26	0	12	0	24	5	19	0	26	2	10	5	23	2	26	4	18	0	15	0	26	0	12	0	23	0	26	5
	A											0	5	0	5	14	5	2	0	7	5	0	3	16	0	3	3	0	1	8	5	11	5	0	5	14	5	3	5	0	0
(39)	P													26	0	12	0	24	5	19	0	26	2	10	5	23	2	26	4	18	0	15	0	26	0	12	0	23	0	26	5
	A													0	5	14	5	2	0	7	5	0	3	16	0	3	3	0	1	8	5	11	5	0	5	14	5	3	5	0	0
(42)	P															12	0	24	5	19	0	26	2	10	5	23	2	26	4	18	0	15	0	26	0	12	0	23	0	26	5
	A															14	5	2	0	7	5	0	3	16	0	3	3	0	1	8	5	11	5	0	5	14	5	3	5	0	0
(45)	P																	12	17	10	9	12	16	2	13	12	13	11	18	11	7	4	11	12	14	8	4	12	11	12	19
	A																	0	2	2	10	0	3	10	3	0	3	1	1	1	12	8	8	0	5	4	15	0	8	0	0
(46)	P																			17	2	26	2	14	1	23	2	27	2	16	2	14	1	24	2	10	2	21	2	29	2
	A																			12	0	3	0	15	1	6	0	2	0	13	0	15	1	5	0	19	0	8	0	0	0
(47)	P																					20	8	8	8	19	7	19	10	16	3	10	5	20	7	11	1	16	6	20	11
	A																					0	3	12	3	1	4	1	1	4	8	10	6	0	4	9	10	4	5	0	0

2 by 2 Contingency Tables for Bivalve Species Pairs
Occurrences at Locations on Lines L1, L2, and RL1
P = Present A = Absent

SPECIES

SPECIES		(71)		(72)		(73)		(74)		(76)		(78)		(8)		(84)		(97)		(98)		(100)		(101)		(103)		(104)		(105)		(111)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(28)	P	17	0	26	1	20	0	11	0	30	1	29	0	23	0	11	1	23	0	22	0	29	0	28	1	29	0	17	0	12	0	23	0
	A	13	1	4	0	10	1	19	1	0	0	1	1	7	1	19	0	7	1	8	1	1	1	2	0	1	1	13	1	18	1	7	1
(29)	P	17	1	30	1	20	1	11	1	30	1	30	0	23	0	11	1	23	0	22	1	20	0	30	0	29	0	16	0	12	0	23	0
	A	13	0	0	0	10	0	19	0	0	0	0	1	7	1	19	0	7	1	8	0	1	1	0	1	1	1	14	1	18	1	7	1
(32)	P	16	5	25	6	17	3	10	1	25	6	25	5	21	2	8	4	21	2	20	2	25	4	24	5	25	4	16	0	12	0	21	1
	A	9	1	0	0	8	3	15	5	0	0	0	1	4	3	17	2	4	4	5	4	0	2	1	1	0	2	9	6	13	6	4	5
(33)	P	13	4	15	16	15	5	8	3	15	16	15	15	12	11	1	11	13	10	14	8	15	14	15	15	15	14	13	3	10	2	14	9
	A	2	12	0	0	0	11	7	13	0	0	0	1	3	5	14	5	2	6	1	8	0	2	0	1	0	2	2	13	5	14	1	7
(37)	P	11	6	13	18	12	8	7	4	13	18	13	17	12	11	2	10	13	10	12	10	13	16	12	17	13	16	12	4	9	3	12	11
	A	2	12	0	0	1	10	6	14	0	0	0	1	1	7	11	8	0	8	1	8	0	2	1	1	0	2	1	14	4	15	1	7
(38)	P	17	5	26	5	20	5	11	5	26	5	26	4	15	4	7	5	23	0	23	0	26	3	25	4	26	3	16	0	12	0	23	0
	A	9	0	0	0	6	0	15	0	0	0	0	1	11	1	19	0	3	5	3	5	0	2	1	1	0	2	10	5	14	5	3	5
(39)	P	11	5	26	5	20	5	11	5	26	5	26	4	15	4	7	5	23	0	23	0	26	3	25	4	26	3	16	0	12	0	23	0
	A	9	0	0	0	6	0	15	0	0	0	0	1	11	1	19	0	3	5	3	5	0	2	1	1	0	2	10	5	14	5	3	5
(42)	P	11	5	26	5	20	5	11	5	26	5	26	4	15	4	7	5	23	0	23	0	26	3	25	4	26	3	16	0	12	0	23	0
	A	9	0	0	0	6	0	15	0	0	0	0	1	11	1	19	0	3	5	3	5	0	2	1	1	0	2	10	5	14	5	3	5
(45)	P	10	7	12	19	11	9	5	6	12	19	12	18	9	14	1	11	10	13	11	11	12	17	11	18	12	17	9	7	9	3	11	12
	A	2	12	0	0	1	10	7	13	0	0	0	1	3	5	11	8	2	6	1	8	0	2	1	1	0	2	3	12	3	16	1	7
(46)	P	16	1	29	2	18	2	9	2	29	2	28	2	21	2	12	0	21	2	20	2	27	2	27	2	27	2	14	2	11	1	21	2
	A	13	1	0	0	11	0	20	0	0	0	1	0	8	0	17	2	8	0	9	0	2	0	2	0	2	0	15	0	18	1	8	0
(47)	P	15	2	20	11	15	5	11	0	20	11	[illegible]	0	16	7	4	8	17	6	16	6	20	9	19	10	20	9	14	9	10	2	18	5
	A	5	9	0	0	5	6	9	11	0	0	0	1	4	13	16	3	3	5	4	5	0	2	1	1	0	2	6	2	10	9	2	6

SPECIES		(115)		(116)		(121)		(124)		(125)		(126)		(127)		(128)		(129)		(135)		(138)		(140)		(143)		(146)		(147)		(154)		(156)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(28)	P	29	1	24	0	12	0	28	1	28	0	29	1	11	0	9	0	9	1	19	1	15	0	24	0	20	0	30	1	17	0	29	1
	A	1	0	6	1	18	1	2	0	2	1	1	0	19	1	21	1	21	0	11	0	15	1	6	1	10	1	0	0	13	1	1	0
(29)	P	30	0	24	0	12	0	28	1	28	0	29	1	11	0	9	0	9	1	21	1	15	0	24	1	20	0	30	1	22	1	30	0
	A	0	1	6	1	18	1	2	0	2	1	1	0	19	1	21	1	21	0	9	0	15	1	6	0	10	1	0	0	8	0	0	1
(32)	P	25	5	21	3	11	5	23	6	25	3	24	6	8	3	8	1	7	3	16	5	14	1	22	2	17	3	25	6	20	2	25	5
	A	0	1	4	3	14	1	2	0	0	3	1	0	17	3	17	5	18	3	9	1	11	5	3	4	8	3	0	0	5	4	0	1
(33)	P	15	15	14	10	4	8	14	13	15	13	14	16	7	4	8	1	7	4	5	15	13	2	12	12	13	7	15	6	15	7	15	15
	A	0	1	1	6	11	8	1	3	0	3	1	0	8	12	7	15	8	12	10	1	2	14	3	4	2	9	0	0	0	9	0	1
(37)	P	13	17	11	13	6	6	12	16	13	15	12	18	4	7	8	1	6	4	5	15	11	4	11	13	12	9	13	18	12	10	13	17
	A	0	1	2	5	7	12	1	2	0	3	1	0	9	11	5	17	7	14	8	3	2	14	2	5	1	9	0	0	1	8	0	1
(38)	P	26	4	24	0	12	0	24	5	26	2	25	5	11	0	9	0	7	3	14	5	15	0	23	1	18	2	26	5	20	1	26	4
	A	0	1	2	5	14	5	2	0	0	3	1	0	14	5	17	5	19	2	12	0	11	5	3	4	8	3	0	0	6	4	0	1
(39)	P	26	4	24	0	12	0	24	5	26	2	25	5	11	0	9	0	7	3	14	5	15	0	23	1	18	2	26	5	20	1	26	4
	A	0	1	2	5	14	5	2	0	0	3	1	0	14	5	17	5	19	2	12	0	11	5	3	4	8	3	0	0	6	4	0	1
(42)	P	26	4	24	0	12	0	24	5	26	2	25	5	11	0	9	0	7	3	14	5	15	0	23	1	18	2	26	5	20	1	26	4
	A	0	1	2	0	14	5	2	0	0	3	1	0	14	5	17	5	19	2	12	0	11	5	3	4	8	3	0	0	6	4	0	1
(45)	P	12	18	11	13	3	9	12	18	12	16	12	18	7	4	6	3	4	6	4	16	11	4	9	15	11	9	12	19	12	10	12	18
	A	0	1	1	6	9	10	1	1	0	3	0	1	5	15	6	16	8	13	8	3	1	15	3	4	1	10	0	0	0	9	0	1
(46)	P	28	2	22	2	10	2	28	1	26	2	29	1	11	0	7	2	9	1	19	1	14	1	22	2	19	1	29	2	20	2	28	2
	A	1	0	7	0	19	0	1	1	3	0	0	1	18	2	22	0	20	1	10	1	15	1	7	0	10	1	0	0	9	0	1	0
(47)	P	20	10	18	6	7	5	19	10	20	8	19	11	13	4	20	0	14	4	10	10	15	1	16	8	16	5	20	11	16	6	20	10
	A	0	1	2	5	13	6	1	1	0	3	1	0	7	7	0	11	6	7	10	1	5	10	4	3	4	6	0	0	4	5	0	1

2 by 2 Contingency Tables for Bivalve Species Pairs
Occurrences at Locations on Lines L1, L2, and RL1
P = Present A = Absent

SPECIES

SPECIES		(51)		(53)		(56)		(57)		(58)		(59)		(62)		(65)		(67)		(71)		(72)		(73)		(74)		(76)		(78)		(83)		(84)		(97)		(98)		(100)		(101)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(48)	P	12	3	24	1	27	2	18	0	15	0	26	0	11	0	23	0	28	3	17	0	28	3	20	0	11	0	28	3	28	2	22	1	9	3	23	0	22	0	28	1	27	2
	A	16	0	4	2	1	1	10	3	13	3	2	3	17	3	5	3	0	0	11	3	0	0	8	3	17	3	0	0	0	1	6	2	19	0	5	3	6	3	0	2	1	1
(51)	P			12	13	14	16	8	10	7	8	9	16	4	8	8	15	15	16	7	10	15	16	8	13	5	5	15	16	14	16	11	10	11	1	10	13	10	12	13	16	14	15
	A			3	3	1	0	7	6	8	8	6	0	11	8	7	1	0	0	8	6	0	0	7	3	10	11	0	0	1	0	4	6	4	15	5	3	5	4	2	0	1	1
(53)	P					25	4	17	1	12	3	23	3	12	0	21	2	26	5	16	1	26	5	19	1	10	1	26	5	26	4	20	3	9	3	20	3	21	1	25	4	26	4
	A					1	1	9	4	14	1	3	1	14	5	5	3	0	0	10	4	0	0	7	4	16	4	0	0	0	1	6	2	17	2	6	2	5	4	1	1	0	1
(56)	P							17	1	14	1	25	1	11	1	22	1	29	2	16	1	29	2	19	1	10	1	29	2	29	1	22	1	11	1	23	1	21	1	28	1	29	0
	A							12	1	15	1	4	1	18	1	7	1	0	0	13	1	0	0	10	1	19	1	0	0	0	1	7	1	18	1	6	1	8	1	1	1	0	2
(57)	P									9	5	18	8	11	1	17	6	18	13	14	4	18	3	16	4	10	1	18	13	18	12	16	7	3	9	17	6	17	5	10	10	17	12
	A									9	8	0	5	7	12	1	7	0	0	4	9	0	0	2	9	8	12	0	0	0	1	2	6	15	4	1	7	1	8	8	3	1	1
(58)	P											15	11	7	5	13	10	15	16	8	9	15	16	10	10	7	4	15	16	15	15	15	8	5	7	14	9	13	9	15	14	14	15
	A											0	5	8	11	2	6	0	0	7	5	0	0	5	6	8	12	0	0	0	1	0	8	10	9	1	7	2	7	0	2	1	1
(59)	P													12	0	23	0	26	5	17	0	26	5	20	0	11	0	26	5	26	4	22	1	7	5	23	0	22	0	26	3	25	4
	A													14	5	3	5	0	0	9	5	0	0	6	5	15	5	0	0	0	1	4	4	19	0	3	5	4	5	0	2	1	1
(62)	P															12	11	12	19	11	15	12	19	11	9	7	4	12	19	12	18	12	11	1	11	12	11	12	13	12	17	11	18
	A															0	8	0	0	1	4	0	0	1	10	5	15	0	0	0	1	0	8	11	8	0	8	0	6	0	2	1	1
(65)	P																	24	7	19	2	24	7	19	1	11	0	24	7	24	6	21	2	5	7	22	2	21	2	24	5	23	6
	A																	0	1	5	5	0	0	5	6	13	7	0	0	0	1	3	4	19	0	2	5	3	5	0	2	1	1
(67)	P																			17	0	31	0	20	0	11	0	31	0	30	0	23	0	12	0	23	0	22	0	29	0	29	0
	A																			14	0	0	0	11	0	20	0	0	0	1	0	8	0	9	0	8	0	9	0	2	0	2	0
(71)	P																					17	14	15	5	9	2	17	14	17	13	14	9	5	7	16	7	15	7	17	12	16	13
	A																					0	0	2	9	9	12	0	0	0	1	3	5	12	7	1	7	2	7	0	2	1	1

SPECIES

SPECIES		(103)		(104)		(105)		(111)		(115)		(116)		(121)		(124)		(125)		(126)		(127)		(128)		(129)		(135)		(138)		(140)		(143)		(146)		(147)		(154)		(156)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(48)	P	28	1	16	0	12	0	23	0	28	2	24	0	12	0	25	3	28	1	27	3	11	0	9	0	7	3	17	2	15	0	24	0	20	1	28	3	22	0	28	2	25	0
	A	0	2	12	3	16	3	5	3	0	1	4	3	16	3	3	0	0	2	1	0	17	3	19	3	21	0	1	1	13	3	4	3	8	2	0	0	6	3	0	1	3	3
(51)	P	13	16	6	10	5	7	8	15	14	16	10	14	5	7	15	14	12	16	15	15	2	9	5	4	2	8	7	13	5	10	13	9	7	12	15	16	7	15	14	16	10	15
	A	3	0	11	6	10	9	7	1	1	0	5	2	10	9	0	2	3	0	0	1	13	7	10	12	13	8	8	3	10	6	2	7	8	4	0	0	8	1	1	0	5	1
(53)	P	25	4	15	1	12	0	20	3	26	4	21	3	9	3	24	4	25	3	25	5	9	2	9	0	8	2	16	4	15	0	21	3	19	1	26	5	20	2	26	4	22	3
	A	1	1	11	4	13	5	6	2	0	1	5	2	17	2	2	1	1	2	1	0	17	3	17	5	18	3	10	1	10	5	5	2	7	4	0	0	6	3	0	1	4	2
(56)	P	28	0	15	1	11	1	22	1	29	1	23	1	12	0	29	2	27	1	28	2	11	0	8	1	9	1	18	2	14	1	23	1	19	1	29	2	21	1	29	1	25	0
	A	1	2	14	1	18	1	7	1	0	1	6	1	17	2	0	0	2	1	1	0	18	2	21	1	20	1	11	0	15	1	10	1	10	1	0	0	8	1	0	1	4	2
(57)	P	18	11	14	2	11	1	18	5	18	12	18	6	8	4	16	13	18	10	17	13	7	4	8	1	7	3	9	11	13	2	16	8	13	7	18	13	17	5	18	12	18	7
	A	0	2	4	11	7	12	0	8	0	1	0	7	10	9	2	0	0	3	1	0	11	9	10	12	11	10	9	2	5	11	2	5	5	6	0	0	1	8	0	1	0	6
(58)	P	15	14	9	7	7	6	14	8	15	15	14	7	9	3	14	15	15	13	15	15	4	7	4	5	4	6	11	9	6	9	15	9	11	9	15	16	12	10	15	15	14	11
	A	0	2	6	9	8	10	1	8	0	1	1	7	6	12	1	1	0	3	0	1	11	9	11	11	11	10	4	7	9	7	0	7	4	7	0	0	3	6	0	1	1	5
(59)	P	26	3	16	0	12	0	23	0	26	4	24	0	12	0	24	5	26	1	25	5	11	0	9	0	7	3	15	5	15	0	23	1	18	2	26	5	21	1	26	4	24	1
	A	0	2	10	5	14	5	3	5	0	1	1	5	14	5	2	0	0	4	1	0	14	5	17	5	19	2	9	0	11	5	3	4	8	3	0	0	5	4	0	1	2	4
(62)	P	12	17	11	5	9	3	12	11	12	18	12	12	5	7	10	18	12	16	11	19	3	8	8	1	6	4	5	16	9	6	2	14	9	11	12	19	10	10	12	18	11	11
	A	0	2	1	14	3	16	0	8	0	1	0	7	7	12	2	1	0	3	1	0	9	11	4	11	6	15	7	3	3	13	10	5	3	8	0	0	2	9	0	1	1	8
(65)	P	24	5	16	0	11	1	21	2	24	6	22	2	12	1	21	7	24	4	23	7	11	0	9	0	7	3	13	7	14	1	21	3	19	1	24	7	21	1	24	6	23	5
	A	0	2	8	7	13	6	3	5	0	1	2	5	12	6	3	0	0	3	1	0	13	7	15	7	17	4	11	0	10	6	3	4	5	6	0	0	3	6	0	1	1	2
(67)	P	29	0	16	0	12	0	23	0	30	0	24	0	12	0	29	0	28	0	30	0	11	0	9	0	10	0	20	0	15	0	24	0	20	0	31	0	22	0	30	0	25	0
	A	2	0	15	0	19	0	8	0	1	0	7	0	19	0	2	0	3	0	1	0	20	0	22	0	21	0	11	0	16	0	7	0	11	0	0	0	9	0	1	0	6	0
(71)	P	17	12	13	3	11	1	15	8	17	13	16	8	5	7	17	12	17	11	17	13	6	5	8	1	4	6	9	11	13	2	16	9	13	7	17	14	13	9	17	13	15	10
	A	0	2	4	11	6	13	2	6	0	1	1	6	12	7	0	2	0	3	0	1	11	9	9	13	13	8	8	3	4	12	1	5	4	7	0	0	4	5	0	1	2	4

2 by 2 Contingency Tables for Bivalve Species Pairs
Occurrences at Locations on Lines L1, L2, and RL1
P = Present A = Absent

SPECIES

SPECIES		(73)		(74)		(76)		(78)		(83)		(84)		(97)		(98)		(100)		(101)		(103)		(104)		(105)		(111)		(115)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(72)	P	20	0	11	0	31	0	30	0	23	0	12	0	23	0	22	0	29	0	29	0	29	0	16	0	12	0	23	0	30	0
	A	11	0	20	0	0	0	1	0	8	0	9	0	8	0	9	0	2	0	2	0	2	0	15	0	19	0	8	0	1	0
(73)	P			9	2	20	11	20	10	17	16	5	7	18	6	18	4	20	9	19	10	20	9	12	4	11	1	17	6	20	10
	A			11	9	0	0	0	1	3	5	15	4	2	5	2	7	0	2	1	1	0	2	8	7	9	10	3	5	0	1
(74)	P					11	20	11	17	11	12	3	10	11	12	9	13	11	18	10	19	11	18	9	7	6	6	9	14	11	19
	A					0	0	0	1	0	8	8	10	0	8	2	7	0	2	1	1	0	2	2	13	5	15	2	6	0	1
(76)	P							30	0	23	0	12	0	23	0	22	0	29	0	29	0	29	0	16	0	12	0	23	0	30	0
	A							1	0	8	0	9	0	8	0	9	0	2	0	2	0	2	0	15	0	19	0	8	0	1	0
(78)	P									23	0	11	1	23	0	23	0	29	0	29	0	29	0	16	0	12	0	23	0	30	0
	A									7	1	9	0	7	1	7	1	1	1	1	1	1	1	4	1	8	1	7	1	0	1
(83)	P											7	5	20	2	17	4	23	6	22	7	23	6	16	1	11	1	20	3	23	7
	A											16	3	3	6	6	4	0	2	1	1	0	2	7	7	17	7	3	5	0	1
(84)	P													6	17	5	18	2	19	11	18	10	19	1	15	2	10	5	18	11	19
	A													6	2	7	1	10	0	1	1	2	0	11	4	10	9	7	1	1	0
(97)	P															22	3	23	6	23	7	23	6	16	0	11	1	21	2	23	7
	A															1	5	0	2	0	1	0	2	7	8	12	7	2	6	0	1
(98)	P																	22	7	21	8	22	7	14	2	11	1	21	3	3	8
	A																	0	2	1	1	0	2	8	7	11	8	1	6	0	1
(100)	P																			28	1	29	0	16	0	12	0	23	0	29	1
	A																			1	1	0	2	13	2	17	2	6	2	0	1
(101)	P																					28	1	15	1	11	1	22	1	29	1
	A																					1	1	14	1	18	1	7	1	0	1

SPECIES		(116)		(121)		(124)		(125)		(126)		(127)		(128)		(129)		(135)		(138)		(140)		(143)		(146)		(147)		(154)		(156)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(72)	P	24	0	12	0	29	0	28	0	30	0	11	0	9	0	10	0	20	0	15	0	24	0	20	0	31	0	22	0	30	0	25	0
	A	7	0	19	0	2	0	3	0	1	0	20	0	22	0	21	0	11	0	16	0	7	0	11	0	0	0	9	0	1	0	6	0
(73)	P	19	5	5	7	19	10	20	8	19	11	10	1	9	0	7	3	10	11	12	2	17	7	16	4	20	11	17	5	20	10	19	6
	A	1	6	15	4	1	1	0	3	1	0	10	10	11	11	13	8	10	0	8	9	3	4	4	7	0	0	3	6	0	1	1	5
(74)	P	11	14	5	7	10	19	11	17	10	20	4	7	7	2	4	6	6	14	7	8	11	7	9	9	11	20	9	13	11	19	10	15
	A	0	6	6	13	1	1	0	3	1	0	7	13	4	18	7	14	5	6	4	12	0	13	2	11	0	0	2	7	0	1	1	5
(76)	P	24	0	12	0	29	0	28	0	30	0	11	0	9	0	10	0	20	0	15	0	24	0	20	0	31	0	22	0	30	0	25	0
	A	7	0	19	0	2	0	3	0	1	0	20	0	22	0	21	0	11	0	16	0	7	0	11	0	0	0	9	0	1	0	6	0
(78)	P	24	0	12	0	28	1	28	0	29	1	11	0	9	0	9	1	20	1	15	0	24	0	20	0	30	0	22	0	30	0	25	0
	A	6	1	18	1	2	0	2	1	1	0	19	1	21	1	21	0	10	0	5	1	6	1	10	1	0	1	8	1	0	1	5	1
(83)	P	22	3	12	0	21	8	23	5	22	8	8	3	9	0	7	3	15	5	11	4	20	5	14	6	23	8	18	4	23	7	21	4
	A	1	5	11	8	2	0	0	3	1	0	15	5	14	8	16	5	8	3	12	4	3	3	9	2	0	0	5	4	0	1	2	4
(84)	P	7	17	3	9	12	16	9	19	12	18	2	9	1	8	5	5	11	9	2	13	8	16	6	13	12	19	3	19	11	19	7	18
	A	5	2	9	10	0	3	3	0	0	1	10	10	11	11	7	14	1	10	10	6	4	3	6	6	0	0	9	0	1	0	5	1
(97)	P	22	3	12	0	20	8	23	3	22	7	8	3	9	0	7	3	7	6	13	2	21	3	16	4	23	8	18	4	23	7	21	4
	A	1	5	11	8	3	0	0	5	1	0	15	5	14	8	16	5	16	2	10	6	2	5	7	4	0	0	5	4	0	1	2	4
(98)	P	22	4	10	2	20	9	22	6	21	9	8	3	8	1	7	3	12	8	13	1	19	5	16	4	22	9	19	2	22	8	20	5
	A	0	5	12	7	2	0	0	3	1	0	14	6	14	3	15	6	10	1	9	8	3	4	6	5	0	0	3	7	0	1	2	4
(100)	P	24	0	12	0	27	2	28	2	28	2	11	0	9	0	8	2	18	2	15	0	24	0	20	0	29	2	22	0	29	1	25	0
	A	5	2	17	2	2	0	1	0	1	0	18	2	20	2	21	0	11	0	14	2	5	2	9	2	0	0	7	2	0	1	4	2
(101)	P	23	1	12	0	26	2	27	1	28	2	11	0	8	1	9	1	19	2	14	1	23	1	18	1	29	2	21	1	29	1	24	1
	A	6	1	17	2	3	0	2	1	1	0	18	2	21	1	20	1	10	0	15	1	6	1	11	1	0	0	8	1	0	1	5	1

2 by 2 Contingency Tables for Bivalve Species Pairs
Occurrences at Locations on Lines L1, L2, and RL1
P = Present A = Absent

SPECIES

SPECIES		(104)		(105)		(111)		(115)		(116)		(121)		(124)		(125)		(126)		(127)		(128)		(129)		(135)		(138)		(140)		(143)		(146)		(147)		(154)		(156)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(103)	P	16	0	12	0	23	0	29	1	24	0	12	0	27	2	28	2	28	2	11	0	9	0	8	2	18	2	15	0	24	0	20	0	29	2	22	0	29	1	25	0
	A	13	2	17	2	6	2	0	1	5	2	17	2	2	0	1	0	1	0	8	2	20	2	21	0	11	0	14	2	5	2	9	2	0	0	7	2	0	1	4	2
(104)	P			9	3	15	8	16	14	14	10	6	4	15	13	16	12	15	15	6	5	9	0	6	4	8	13	12	3	14	10	12	8	16	15	16	6	16	14	15	11
	A			7	12	1	7	0	1	2	5	10	11	1	2	0	3	1	0	10	10	7	15	10	11	8	2	4	12	2	5	4	7	0	0	0	9	0	1	1	4
(105)	P					12	11	12	18	12	12	5	6	10	18	12	16	11	19	4	7	8	1	4	6	5	15	9	6	8	15	9	11	12	19	11	11	12	18	11	11
	A					0	8	0	1	0	7	7	13	2	1	0	3	1	0	8	12	4	18	8	13	7	4	3	13	1	4	3	8	0	0	1	8	0	1	1	8
(111)	P							23	7	22	0	12	0	21	8	23	5	22	8	8	3	9	0	7	3	14	7	13	1	20	4	16	7	23	8	19	3	23	7	21	4
	A							0	1	1	8	11	8	2	0	0	3	1	0	15	5	14	8	16	5	9	1	10	7	3	4	7	1	0	0	4	5	0	1	2	4
(115)	P									24	0	12	0	27	1	28	0	29	1	11	0	9	0	9	1	19	1	15	0	24	0	20	0	30	1	22	0	30	0	25	0
	A									6	1	8	1	3	0	2	1	1	0	19	1	21	1	21	0	11	0	15	1	6	1	10	1	0	0	8	1	0	1	5	1
(116)	P											11	1	22	7	24	4	23	7	10	1	9	0	7	4	15	6	14	1	22	2	19	2	24	7	20	2	24	6	24	2
	A											13	6	2	0	0	3	1	0	14	6	15	8	17	3	9	1	10	6	2	5	5	5	0	0	4	5	0	1	0	5
(121)	P													10	19	12	16	10	19	3	8	4	5	4	6	10	11	4	11	6	13	8	12	12	19	9	13	12	18	12	13
	A													2	0	0	3	2	0	9	11	8	14	8	13	2	8	8	8	6	6	4	7	0	0	3	6	0	1	0	6
(124)	P															28	2	29	1	11	0	8	1	10	0	19	1	15	0	22	2	18	2	29	2	20	2	28	2	23	2
	A															1	0	0	1	18	2	21	1	19	2	10	1	14	2	7	0	11	0	0	0	9	0	1	0	6	0
(125)	P																	27	3	11	0	9	0	7	3	17	3	15	0	24	0	20	0	28	3	22	0	28	2	25	0
	A																	1	0	17	3	19	3	21	0	11	0	13	3	4	3	8	3	0	0	6	3	0	1	3	3
(126)	P																			11	0	8	1	10	0	20	0	15	0	23	1	19	1	30	1	21	1	29	1	24	1
	A																			19	1	22	0	20	1	10	1	15	1	7	0	11	0	0	0	9	0	1	0	6	0
(127)	P																					5	6	2	8	7	14	7	8	9	13	8	10	13	18	10	11	13	18	11	14
	A																					8	12	11	10	6	4	6	10	4	5	5	8	0	0	3	7	0	1	2	4

SPECIES		(129)		(135)		(138)		(140)		(143)		(146)		(147)		(154)		(156)	
		P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A
(128)	P	5	5	4	16	8	7	8	16	7	13	9	22	9	13	9	21	8	17
	A	4	17	5	6	1	15	1	6	2	9	0	0	0	9	0	1	1	5
(129)	P			6	14	6	9	5	19	6	14	10	21	6	16	9	21	7	18
	A			4	7	4	13	5	2	4	7	0	0	4	5	1	0	3	3
(135)	P					6	9	16	9	11	9	20	11	11	11	19	11	14	11
	A					14	2	4	2	9	2	0	0	9	0	1	0	6	0
(138)	P							12	12	11	9	15	16	14	8	15	15	13	12
	A							3	4	4	7	0	0	1	8	0	1	2	4
(140)	P									16	4	24	7	19	3	24	6	22	3
	A									8	3	0	0	5	4	0	1	2	4
(143)	P											20	11	16	6	20	10	18	7
	A											0	0	4	5	1	1	2	4
(146)	P													22	3	30	0	25	0
	A													9	0	1	0	6	0
(147)	P															22	8	21	4
	A															0	1	1	4
(154)	P																	25	5
	A																	0	1

2 by 2 Contingency Tables for Bivalve Species Pairs
Occurrences at Locations on Lines L1, L2, and RL1
P = Present A = Absent

SPECIES IDENTIFICATION
FOR 2 BY 2 CONTINGENCY TABLES

(1) Abra aequalis
(2) Abra nuculoidea
(7) Anatina lineata
(9) Anodontia alba
(10) Anodontia alba (juv.)
(11) Anomia simplex
(12) Anadara ovalis (juv.)
(13) Noetia ponderosa (juv.)
(17) Atrina serrata
(24) Chama congregata
(26) Chione cancellata
(28) Chione grus
(29) Chione intapurpurea
(32) Corbula swiftiana
(33) Corbula dietziana
(37) Corbula barrattiana
(38) Corbula krebsiana
(39) Varicorbula operculata
(42) Crassinella lunulata
(45) Cuspidaria ornatissima
(46) Dinocardium robustum
(47) Diplodonta punctatus
(48) Diplodonta nucleiformis
(51) Donax variabilis
(53) Dosinia elegans
(56) Ensis minor
(57) Erycina floridana
(58) Eucrassitella speciosa
(59) Gouldia cerina
(62) Glycymeris pectinata
(65) Laevicardium laevigatum
(67) Laevicardium pictum
(71) Parvilucina amiantus
(72) Lucina multilineata
(73) Lucina nassula
(74) Lucina pensylvanica
(76) Lucina radians
(78) Cavilucina trisulcatus
(83) Macrocallista maculata
(84) Macrocallista nimbosa
(97) Nucula proxima
(98) Nuculana acuta
(100) Pandora arenosa
(101) Pandora trilineata
(103) Aequipecten gibbus
(104) Pecten muscosus
(105) Pecten raveneli
(111) Plicatula gibbosa
(115) Scapharca transversa
(116) Semele bellastriata
(121) Arcinella cornuta (juv.)
(124) Ervilia concentrica
(125) Transennella sp.
(126) Montecuta floridana
(127) Cooperella atlantica
(128) Ensitellops protexta
(129) Spisula solidissima
(135) Strigilla mirabilis
(138) Tellina alternata
(140) Tellina interrupta
(143) Tellina lintea
(146) Tellina spp.
(147) Thyasira trisinuata
(154) Venericardia tridentata
(156) Verticordia ornata

APPENDIX G

NUMBERS OF LEFT AND RIGHT VALVES AND CALCULATED CHI-SQUARE TEST STATISTICS

SAMPLES

	L111	L112	L113	L114	L121	L122	L123	L124	L131	L132	L133	L134	L141	L142	L143	L144	L151	L152	L153	L154
Right	93	133	132	151	246	225	254	131	244	177	157	228	153	136	202	207	138	130	86	120
Left	111	117	114	139	277	238	231	130	220	149	120	195	164	122	199	170	124	117	92	129

	L161	L162	L163	L164	L171	L172	L173	L174	L181	L182	L183	L184	L191	L192	L193	L194	L1101	L1102	L1103	L1104
Right	117	152	121	133	102	82	97	121	86	48	47	70	45	37	48	44	46	30	44	23
Left	103	138	116	136	107	73	117	111	96	61	57	65	44	43	39	46	36	34	43	23

Chi-square = 32.56 w/ 39 d.f.

Total Numbers of Left and Right Valves - Line L1

SAMPLES

	L211	L212	L213	L214	L221	L222	L223	L224	L231	L232	L233	L234	L241	L242	L243	L244	L251	L252	L253	L254
Right	109	156	171	144	152	113	139	127	124	123	111	142	165	156	111	103	132	118	88	136
Left	101	146	168	140	140	117	156	112	118	128	108	150	202	130	107	98	124	126	87	170

	L261	L262	L263	L264	L271	L272	L273	L274	L281	L282	L283	L284	L291	L292	L293	L294	L2101	L2102	L2103	L2104
Right	188	151	178	158	124	85	176	122	93	126	163	132	54	69	45	49	4	7	7	10
Left	178	163	188	164	111	93	153	152	100	131	140	118	52	64	53	50	1	7	7	12

Chi-square = 27.42 w/ 39 d.f.

Total Numbers of Left and Right Valves - Line L2

SAMPLES

	RL111	RL112	RL121	RL122	RL131	RL132	RL141	RL142	RL151	RL152	RL161	RL162	RL171	RL172	RL181	RL182	RL191
Right	238	344	268	256	237	229	259	518	227	205	281	177	233	147	238	279	257
Left	246	259	243	219	236	205	265	458	209	188	301	183	229	121	243	290	266

	RL192	RL1101	RL1102	RL1111	RL1112
Right	242	292	238	320	234
Left	276	314	246	334	242

Chi-square = 37.76* w/ 21 d.f.

Total Numbers of Left and Right Valves - Line RL1

Scapharca transversa

	L221	L224	L234	L233	L231	L243	L242	L241	L244	L252	L253	L254	L251	L262	L261	L263
Left	40	31	35	26	41	31	28	44	31	19	25	13	19	8	14	5
Right	41	26	25	17	35	19	26	35	11	5	22	7	8	3	9	3

Chi-square = 17.13 w/ 15 d.f.

Laevicardium pictum

	L221	L224	L234	L233	L231	L243	L242	L241	L244	L252	L253	L254	L251	L262	L261	L263
Left	17	18	26	14	15	14	24	26	17	5	21	9	2	11	6	9
Right	14	7	20	4	14	19	28	18	19	2	22	6	7	6	10	10

Chi-square = 19.66 w/ 15 d.f.

Chione intapurpurea

	L221	L224	L234	L233	L231	L243	L242	L241	L244	L252	L253	L254	L251	L262	L261	L263
Left	26	9	15	18	16	16	30	20	17	7	20	13	7	7	13	13
Right	27	10	20	5	4	12	23	24	15	5	16	11	10	5	15	5

Chi-square = 19.45 w/ 15 d.f.

Venericardia tridentata

	L231	L243	L242	L241	L244	L252	L253	L254	L251	L262	L261	L263
Left	39	42	63	79	49	22	25	21	23	24	50	38
Right	39	48	57	79	43	32	29	31	24	25	54	27

Chi-square = 7.05 w/ 11 d.f.

APPENDIX H

ANALYSES OF VARIANCE

		Variable (1)		Variable (2)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	109.512	1.46	24.089	0.69
Location (B)	9	170.814	2.27	45.765	1.31
Interaction (AB)	9	75.918	6.84**	34.827	12.25**
Samples/AB	60	10.972		2.842	
Total	79				

		Variable (3)		Variable (4)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	201.929	16.89**	67.161	0.41
Location (B)	9	44.281	3.70**	830.283	5.09**
Interaction (AB)	9	20.529	1.72	163.112	10.70**
Samples/AB	60	11.950		15.245	
Total	79				

		Variable (5)		Variable (6)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	14.828	0.54	18.598	1.39
Location (B)	7	245.843	8.91**	108.989	8.12**
Interaction (AB)	7	27.587	6.02**	13.341	4.02**
Samples/AB	48	4.58		3.317	
Total	63				

		Variable (7)		Variable (8)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	10.320	2.04	248.456	9.70*
Location (B)	7	133.228	26.31**	362.084	14.14**
Interaction (AB)	7	5.064	2.32	25.600	5.72**
Samples/AB	48	2.183		4.473	
Total	63				

ANALYSES OF VARIANCE

		Variable (9)		Variable (10)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	68.476	16.39**	21.032	2.51
Location (B)	7	62.398	14.93**	98.945	11.81**
Interaction (AB)	7	0.153	0.04	8.381	3.94**
Samples/AB	48	4.178		2.125	
Total	63				

		Variable (11)		Variable (12)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	159.200	14.44**	16.129	0.60
Location (B)	4	891.170	80.80**	2755.760	102.63**
Interaction (AB)	4	19.820	1.79	21.935	0.82
Samples/AB	30	11.029		26.852	
Total	39				

		Variable (13)		Variable (14)	
Sources of Variation	d.f.	MS	F	MS	F
Traverse line (A)	1	479.610	6.39*	56.437	2.28
Location (B)	7	151.004	2.01	196.099	7.90**
Interaction (AB)	7	75.065	12.18**	24.809	2.89*
Samples/AB	48	6.166		8.565	
Total	63				

		Variable (15)	
Sources of Variation	d.f.	MS	F
Traverse line (A)	1	59.185	2.34
Location (B)	5	167.493	6.62*
Interaction (AB)	5	25.300	6.89**
Samples/AB	36	3.668	
Total	47		

* $p < .05$
** $p < .01$

VARIABLES IN
ANALYSES OF VARIANCE

(1) Percent bivalve shells (unbroken + broken).

(2) Percent gastropods and gastropod fragments.

(3) Percent Plagiobrissus grandis fragments.

(4) Percent Encope spp. fragments.

(5) Relative frequency of Chione intapurpurea shells (>2.38mm.) among identified bivalves.

(6) Relative frequency of Anomia simplex shells, as above.

(7) Relative frequency of Scapharca transversa shells, as above.

(8) Relative frequency of Venericardia tridentata shells, as above.

(9) Relative frequency of Laevicardium pictum shells, as above.

(10) Relative frequency of Cavilucina trisulcatus shells, as above.

(11) Relative frequency of Ervilia concentrica shells, as above.

(12) Relative frequency of Donax variabilis shells, as above.

(13) Relative frequency of Lucina multilineata shells, as above.

(14) Relative frequency of Tellina spp. shells, as above.

(15) Relative frequency of Corbula krebsiana + Varicorbula operculata shells, as above.

APPENDIX I

ANALYSES OF CORRELATION

Linear Correlation Coefficients (r)

Variables	(2)	(3)	(4)	(5)
(1)	-.47	.61	-.76**	.34
(2)		-.80**	.78**	.33
(3)			-.89**	-.28
(4)				.05

Variables

Variables

(1) Water depth
(2) Terrigenous sediment grain size (Ø)
(3) Ratio bivalve fragments/unbroken + broken bivalve shells
(4) Percent well preserved bivalve shells
(5) Percent biogenic material 2.38-7.93mm.

** $p < .01$

APPENDIX J

FISHER EXACT PROBABILITY TABLES
ARTICULATED VERSUS LIVING BIVALVES

LIVING

		(1)		(2)		(3)		(4)		(5)		(6)	
		P	A	P	A	P	A	P	A	P	A	P	A
ARTIC.	P	2	7	4	14	2	13	0	6	6	3	1	9
	A	7	5	3	0	4	2	8	7	6	6	3	8

(1) Laevicardium pictum P >.095
(2) Lucina radians P =.026
(3) Cavilucina trisulcatus P =.033
(4) Venericardia tridentata P =.032
(5) Tellina spp. P >.264
(6) Crassinella lunulata P >.275

APPENDIX K

ANALYSIS OF BIVALVE FREQUENCY DATA
SEMIQUANTITATIVE SAMPLES

Computer Punched Card Format

Col 1-7 Sample number

Lines L1 and RL1

Col 1-3 Line number
4-5 Location
6-7 Sample within location

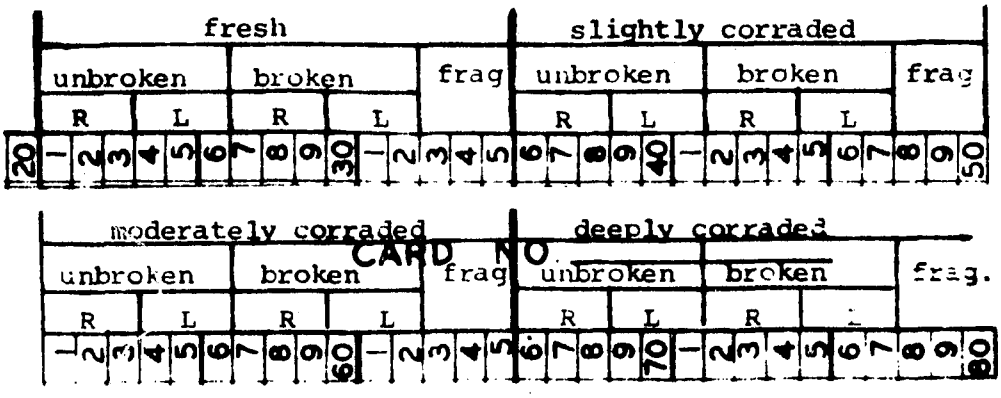
Line L2

Col 1-2 Line number
3-4 Location
6-7 Sample within location

Col 8 Mesh number
1 - >64.0mm.
2 - 15.85-64.0mm.
3 - 7.93-15.85mm.
4 2.38-7.93mm.

9-20 Alpha species name or grain type abbreviation

21-80 DATA



Computer Programs

1-3 Summation programs for line L1, L2, and RL1 data respectively.

Tape output - Nine sums for each punched card. Sums are identified in the program (see following pages). Mesh number 4 frequencies are corrected from split to whole sample. Data is summed within and among 4 preservation catagories without regard to breakage or right/left valve.

4 Sort

Tape output - Above sums sorted by species and sample number.

5 Tables - Frequency and relative frequency of bivalve species on lines L1 and L2, summed across mesh.

Output - Eight frequency and eight relative frequency tables by species and sample number for each line.
Tables
1) Fresh valves excluding fragments
2) Slightly corraded valves excluding fragments
3) Moderately corraded valves excluding fragments
4) Severely corraded valves excluding fragments
5) All fragments
6) Fresh + slightly corraded valves (1+2)
7) Moderately + severely corraded valves (3+4)
8) All broken + unbroken valves (6+7)

6 Tables - As above for line RL1.

PROGRAM (1)

```
C       SUM(1)=FRESH EXCLUDING FRAGMENTS
C       SUM(2)=SLIGHTLY CORRADED EXCLUDING FRAGMENTS
C       SUM(3)=MODERATELY CORRADED EXCLUDING FRAGMENTS
C       SUM(4)=DEEPLY CORRADED EXCLUDING FRAGMENTS
C       SUM(5)=ALL FRAGMENTS
C       SUM(6)=SUM(1)+SUM(2)
C       SUM(7)=SUM(3)+SUM(4)
C       SUM(8)=SUM(6)+SUM(7)
C       SUM(9)=SUM(8)+SUM(5)
        DIMENSION CORFAC(10,4),TOTSUM(10,4)
        DIMENSION SUM(9),NAME(3),VAL(20),ZUM(7)
        INTEGER ST,VAL
        DATA CORFAC/4.05,4.08,2.03,2.14,1.99,2.38,1.00,1.00,1.00,1.00,
       11.98,3.64,4.22,4.03,2.04,2.15,1.00,1.00,1.00,1.00,3.14,5.10,
       24.24,1.95,3.91,1.31,1.00,1.00,1.00,1.00,3.22,3.78,1.95,1.96,
       34.08,1.36,1.00,1.00,1.00,1.00/
        WRITE (6,997)
  997   FORMAT (' ')(MOUNT SGGS26 FILE 1')
        WRITE (6,998)
  998   FORMAT (' ')(0,8,W80,R480')
   20   READ (5,10,END=65) ST,LOC,MESH,NAME,(VAL(I),I=1,20)
   10   FORMAT(3X,2I2,I1,3A4,20I3)
        CORREC=1.
        IF(MESH.NE.4)GOTO 30
        CORREC=CORFAC(ST,LOC)
   30   SUM(1)=(VAL(1)+VAL(2)+VAL(3)+VAL(4))*CORREC
        SUM(2)=(VAL(6)+VAL(7)+VAL(8)+VAL(9))*CORREC
        SUM(3)=(VAL(11)+VAL(12)+VAL(13)+VAL(14))*CORREC
        SUM(4)=(VAL(16)+VAL(17)+VAL(18)+VAL(19))*CORREC
        SUM(5)=(VAL(5)+VAL(10)+VAL(15)+VAL(20))*CORREC
        SUM(6)=SUM(1)+SUM(2)
        SUM(7)=SUM(3)+SUM(4)
        SUM(8)=SUM(6)+SUM(7)
        SUM(9)=SUM(5)+SUM(6)+SUM(7)
        WRITE(6,40)ST,LOC,MESH,NAME,(SUM(J),J=1,9)
   40   FORMAT(3X,2I2,I1,3A4,9F6.0)
        GO TO 20
65      WRITE (6,999)
999     FORMAT (' ')(END TAPE OUTPUT')
        STOP
        END
```

PROGRAM (2)

```
//TESTIT JOB (1,1006),'$00982 ADAMS'
$JOB            1006,00982,TEST,TIME=60,PAGES=300
C       SUM(1)=FRESH EXCLUDING FRAGMENTS
C       SUM(2)=SLIGHTLY CORRADED EXCLUDING FRAGMENTS
C       SUM(3)=MODERATELY CORRADED EXCLUDING FRAGMENTS
C       SUM(4)=DEEPLY CORRADED EXCLUDING FRAGMENTS
C       SUM(5)=ALL FRAGMENTS
C       SUM(6)=SUM(1)+SUM(2)
C       SUM(7)=SUM(3)+SUM(4)
C       SUM(8)=SUM(6)+SUM(7)
C       SUM(9)=SUM(8)+SUM(5)
        DIMENSION CORFAC(10,4),TOTSUM(10,4)
        DIMENSION SUM(9),NAME(3),VAL(20),ZUM(7)
        INTEGER ST,VAL
        DATA CORFAC/4.29,4.35,4.22,4.00,2.00,1.68,1.00,1.00,1.00,1.00,
       14.32,4.16,4.28,4.23,2.04,1.93,1.00,1.00,1.00,1.00,8.34,4.50,
       24.23,4.11,3.95,2.04,1.00,1.00,1.00,1.00,4.17,4.13,3.85,4.21,
       32.16,1.00,1.00,1.00,1.00,1.00/
        WRITE (6,997)
  997   FORMAT (' )(MOUNT SGGS26 FILE 1')
        WRITE (6,998)
  998   FORMAT (' )(0,B,W80,R480')
   20   READ (5,10,END=65) ST,LOC,MESH,NAME,(VAL(I),I=1,20)
   10   FORMAT(2X,2I2,1X,I1,3A4,20I3)
        CORREC=1.
        IF(MESH.NE.4)GOTO 30
        CORREC=CORFAC(ST,LOC)
   30   SUM(1)=(VAL(1)+VAL(2)+VAL(3)+VAL(4))*CORREC
        SUM(2)=(VAL(6)+VAL(7)+VAL(8)+VAL(9))*CORREC
        SUM(3)=(VAL(11)+VAL(12)+VAL(13)+VAL(14))*CORREC
        SUM(4)=(VAL(16)+VAL(17)+VAL(18)+VAL(19))*CORREC
        SUM(5)=(VAL(5)+VAL(10)+VAL(15)+VAL(20))*CORREC
        SUM(6)=SUM(1)+SUM(2)
        SUM(7)=SUM(3)+SUM(4)
        SUM(8)=SUM(6)+SUM(7)
        SUM(9)=SUM(5)+SUM(6)+SUM(7)
        WRITE(6,40)ST,LOC,MESH,NAME,(SUM(J),J=1,9)
   40   FORMAT(3X,2I2,I1,3A4,9F6.0)
        GO TO 20
65      WRITE (6,999)
999     FORMAT (' )(END TAPE OUTPUT')
        STOP
        END
```

PROGRAM (3)

```
C       SUM(1)=FRESH EXCLUDING FRAGMENTS
C       SUM(2)=SLIGHTLY CORRADED EXCLUDING FRAGMENTS
C       SUM(3)=MODERATELY CORRADED EXCLUDING FRAGMENTS
C       SUM(4)=DEEPLY CORRADED EXCLUDING FRAGMENTS
C       SUM(5)=ALL FRAGMENTS
C       SUM(6)=SUM(1)+SUM(2)
C       SUM(7)=SUM(3)+SUM(4)
C       SUM(8)=SUM(6)+SUM(7)
C       SUM(9)=SUM(8)+SUM(5)
        DIMENSION CORFAC(11,2),TOTSUM(11,2)
        DIMENSION SUM(9),NAME(3),VAL(20),ZUM(7)
        INTEGER ST,VAL
        DATA CORFAC/8.92,4.25,5.46,4.68,4.25,4.36,4.51,4.13,8.61,4.34,
       14.42,8.35,4.58,7.50,4.20,4.35,4.04,4.32,4.08,8.28,4.40,4.38/
        WRITE (6,997)
  997   FORMAT (' ')(MOUNT SGGS26 FILE 1')
        WRITE (6,998)
  998   FORMAT (' ')(0,B,W80,R480')
  20    READ(5,10) ST,LOC,MESH,NAME,(VAL(I),I=1,20)
        IF (ST .EQ.99) GO TO 65
  10    FORMAT(3X,2I2,I1,3A4,20I3)
        CORREC=1.
        IF(MESH.NE.4)GOTO 30
        CORREC=CORFAC(ST,LOC)
  30    SUM(1)=(VAL(1)+VAL(2)+VAL(3)+VAL(4))*CORREC
        SUM(2)=(VAL(6)+VAL(7)+VAL(8)+VAL(9))*CORREC
        SUM(3)=(VAL(11)+VAL(12)+VAL(13)+VAL(14))*CORREC
        SUM(4)=(VAL(16)+VAL(17)+VAL(18)+VAL(19))*CORREC
        SUM(5)=(VAL(5)+VAL(10)+VAL(15)+VAL(20))*CORREC
        SUM(6)=SUM(1)+SUM(2)
        SUM(7)=SUM(3)+SUM(4)
        SUM(8)=SUM(6)+SUM(7)
        SUM(9)=SUM(5)+SUM(6)+SUM(7)
  40    FORMAT(3X,2I2,I1,3A4,9F6.0)
        WRITE(6,40)ST,LOC,MESH,NAME,(SUM(J),J=1,9)
        GO TO 20
  50    FORMAT(1X,2I2,I1,3A4,7F6.0)
  60    FORMAT(1X,2I2,7F10.0/1X,2I2,7F10.0/5X,7F10.0/5X,F10.0)
  70    FORMAT(1X,I2,4F6.0)
65      WRITE (6,999)
999     FORMAT (' ')(END TAPE OUTPUT')
        STOP
        END
```

PROGRAM (4)

```
//A EXEC SAS,REGION.SAS=180K,TIME.SAS=3
//SAS.STEPLIB DD DSN=SAS.LIBRARY,DISP=SHR
//         DD DSN=SAS.SLIBRARY,DISP=SHR
//SAS.FT02F001 DD UNIT=DISK,DISP=(NEW,PASS),SPACE=(80,(2000,10)),
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=7200),DSN=SASTMP
//SAS.SYSIN DD *
DATA JERVEY;
INPUT STA 3-4 LOC 6 MESH 7 SPECIES $8-19 V1 20-25 V2 26-31 V3 32-37
 V4 38-43 V5 44-49 V6 50-55 V7 56-61 V8 62-67 V9 68-73;
STALOC=STA*10+LOC;
CARDS;
)(MOUNT SGGS 26  FILE 1
)(I
PROC SORT; BY SPECIES STALOC;
PROC PRTPCH PUNCH;
VARIABLES STA LOC MESH SPECIES V1 V2 V3 V4 V5 V6 V7 V8 V9;
PARMCARDS;
(F4.0,F2.0,F2.0,A8,A4,9F6.0)
/*
//B EXEC FORTGCLG,REGION.GO=60K,TIME.GO=1
//FORT.SYSIN DD *
      DIMENSION CARD(20)
      WRITE (6,10)
      REWIND 2
    5 READ (2,20,END=100) CARD
      WRITE (6,20) CARD
      GO TO 5
  100 WRITE (6,30)
      STOP
   10 FORMAT (' )(MOUNT SGGS26 NEXT FILE'/' )(O,B,W80,R480')
   20 FORMAT (20A4)
   30 FORMAT (' )(END TAPE OUTPUT')
      END
```

PROGRAM (5)

```
      INTEGER*2 M1,M2,T,TT
      INTEGER S,V,STA,HS,SPEC
      DIMENSION M1(8,140,10,4),M2(44800),S(3),V(8),HS(3),SPEC(140,3),
     *NUMS(40),I(8,10,4),TT(320)
      EQUIVALENCE (M1(1,1,1,1),M2(1))
      EQUIVALENCE (T(1,1,1),TT(1))
      DATA HS/'ABRA',' AEQ','UALI'/
      J=1
      DO 4 I=1,320
    4 TT(I)=0
      DO 5 I=1,44800
    5 M2(I)=0
      K=0
      DO 6 I=1,10
      DO 6 II=1,4
      K=K+1
    6 NUMS(K)=I*10+II
   21 READ (5,10,END=11) STA,LOC,S,V
      DO 20 I=1,3
      IF (S(I) .NE. HS(I))  GO TO 30
   20 CONTINUE
   25 DO 50 I=1,8
   50 M1(I,J,STA,LOC)=M1(I,J,STA,LOC)+V(I)
      GO TO 21
   30 DO 60 I=1,3
      SPEC(J,I)=HS(I)
   60 HS(I)=S(I)
      J=J+1
      GO TO 25
   11 DO 85 I=1,3
   85 SPEC(J,I)=HS(I)
      DO 200 K=1,8
      DO 200 I=1,J
      DO 200 L=1,10
      DO 200 M=1,4
  200 T(K,L,M)=T(K,L,M)+M1(K,I,L,M)
      DO 100 I=1,8
      WRITE (6,70) T,(NUMS(KL),KL=1,20)
      DO 90 K=1,J
   90 WRITE (6,80) (SPEC(K,L),L=1,3),((M1(I,K,M,N),N=1,4),M=1,5)
      WRITE (6,300) ((T(I,M,N),N=1,4),M=1,5)
      WRITE (6,70) I,(NUMS(KL),KL=21,40)
      DO 937 K=1,J
  937 WRITE (6,80) (SPEC(K,L),L=1,3),((M1(I,K,M,N),N=1,4),M=6,10)
      WRITE (6,300) ((T(I,M,N),N=1,4),M=6,10)
  100 CONTINUE
      DO 400 K=1,8
      DO 400 I=1,J
      DO 400 L=1,10
      DO 400 M=1,4
      IF (T(K,L,M) .LE. 0) GO TO 471
      M1(K,I,L,M)=M1(K,I,L,M)*1000/T(K,L,M)
      GO TO 400
  471 M1(K,I,L,M)=0
  400 CONTINUE
      DO 500 I=1,8
      WRITE (6,70) I,(NUMS(KL),KL=1,20)
      DO 600 K=1,J
  600 WRITE (6,80) (SPEC(K,L),L=1,3),((M1(I,K,M,N),N=1,4),M=1,5)
      WRITE (6,70) I,(NUMS(KL),KL=21,40)
      DO 938 K=1,J
  938 WRITE (6,80) (SPEC(K,L),L=1,3),((M1(I,K,M,N),N=1,4),M=6,10)
  500 CONTINUE
      STOP
   10 FORMAT     (I2,1X,I1,3X,3A4,8(I5,1X))
   70 FORMAT (1H1,62X,'TABLE ',I2////'     SPECIES  ',20(2X,I3)//)
   80 FORMAT (1H ,3A4,1X,20(1X,I4))
  300 FORMAT (1H0,6X,'TOTALS',1X,20(1X,I4))
      END
```

PROGRAM (6)

```
      INTEGER*2 M1,M2,T,TT
      INTEGER S,V,STA,HS,SPEC
      DIMENSION M1(8,140,11,2),M2(24640),S(3),V(8),HS(3),SPEC(140,3),
     *NUMS(22),T(8,11,2),TT(176)
      EQUIVALENCE (M1(1,1,1,1),M2(1))
      EQUIVALENCE (T(1,1,1),TT(1))
      DATA HS/'ABRA',' AEQ','UALI'/
      J=1
      DO 4 I=1,176
    4 TT(I)=0
      DO 5 I=1,24640
    5 M2(I)=0
      K=0
      DO 6 I=1,11
      DO 6 II=1,2
      K=K+1
    6 NUMS(K)=I*10+II
   21 READ (5,10,END=11) STA,LOC,S,V
      DO 20 I=1,3
      IF (S(I) .NE. HS(I))  GO TO 30
   20 CONTINUE
   25 DO 50 I=1,8
   50 M1(I,J,STA,LOC)=M1(I,J,STA,LOC)+V(I)
      GO TO 21
   30 DO 60 I=1,3
      SPEC(J,I)=HS(I)
   60 HS(I)=S(I)
      J=J+1
      GO TO 25
   11 DO 85 I=1,3
   85 SPEC(J,I)=HS(I)
      DO 200 K=1,8
      DO 200 I=1,J
      DO 200 L=1,11
      DO 200 M=1,2
  200 T(K,L,M)=T(K,L,M)+M1(K,I,L,M)
      DO 100 I=1,8
      WRITE (6,70) I,NUMS
      DO 90 K=1,J
   90 WRITE (6,80) (SPEC(K,L),L=1,3),((M1(I,K,M,N),N=1,2),M=1,11)
      WRITE (6,300) ((T(I,M,N),N=1,2),M=1,11)
  100 CONTINUE
      DO 400 K=1,8
      DO 400 I=1,J
      DO 400 L=1,11
      DO 400 M=1,2
  400 M1(K,I,L,M)=M1(K,I,L,M)*1000/T(K,L,M)
      DO 500 I=1,8
      WRITE (6,70) I,NUMS
      DO 600 K=1,J
  600 WRITE (6,80) (SPEC(K,L),L=1,3),((M1(I,K,M,N),N=1,2),M=1,11)
  500 CONTINUE
      STOP
   10 FORMAT     (I2,1X,I1,3X,3A4,8(I5,1X))
   70 FORMAT (1H1,62X,'TABLE ',I2////'     SPECIES  ',22(2X,I3)//)
   80 FORMAT (1H ,3A4,1X,22(1X,I4))
  300 FORMAT (1H0,6X,'TOTALS',1X,22(1X,I4))
      END
```

COMPUTER ABBREVIATIONS

Taxon	Abbreviation
Bivalves	
Abra aequalis	Abra aequali
Abra nuculoidea	Abra lioaca
Aligena texasiana	Aligena texa
Anadara ovalis	Anadara camp
Anadara lienosa	Anadara lien
Anatina lineata	Anatina line
Anatina plicatella	Anatina plic
Anodontia alba	Anodont alba
Anodontia alba (juv.)	Anodont sp
Anomia simplex	Anomia simpl
Anadara ovalis (juv.)	Arca sp
Noetia ponderosa (juv.)	Arca sp 1
Arca umbonata	Arca umbonat
Arca zebra	Arca zebra
Arcopsis adamsi	Arcopsis adm
Atrina serrata	Atrina serra
Barbatia domingensis	Barbatia dom
Barbatia tenera	Barbatia ten
Brachidontes exustus	Brachiod sp
Cardita floridana	Cardita flor
Chama congregata	Chama congre
Chama macerophylla	Chama macero
Chione cancellata	Chione cancl
Chione clenchi	Chione clenc
Chione grus	Chione grus
Chione intapurpurea	Chione intra
Corbula swiftiana	Corbula A
Corbula dietziana	Corbula B
Basterotia floridana	Corbula C
Corbula contracta	Corbula cont
Corbula barrattiana	Corbula diet
Corbula krebsiana	Corbula kreb
Varicorbula operculata	Corbula oper
Crassinella lunulata	Crassinel sp
Cumingia tellinoides	Cumingia tel
Cuspidaria ornatissima	Cuspid ornat
Dinocardium robustum	Dinoc robust
Diplodonta punctatus	Diplod punct
Diplodonta nucleiformis	Diplod spA

Taxon	Abbrevation
Divaricella quadrisulcata	Divaric quad
Donax variabilis	Donax variab
Dosinia discus	Dosinia disc
Dosinia elegans	Dosinia eleg
Arcinella cornuta	Echinoc corn
Ensis minor	Ensis minor
Erycina floridana	Erycina flor
Eucrassitella speciosa	Eucrass spec
Gouldia cerina	Gafrar cerin
Gastrochaena ovata	Gastroch ova
Glycymeris pectinata	Glycym pectn
Hiatella arctica	Hiatella arc
Laevicardium laevigatum	Laevic laevi
Laevicardium mortoni	Laevic mortn
Laevicardium pictum	Laevic pictm
Lithophaga bisulcata	Lithoph bisu
Parvilucina amiantus	Lucina amian
Lucina multilineata	Lucina multi
Lucina nassula	Lucina nassu
Lucina pensylvanica	Lucina penns
Lucina radians (juv.)	Lucina spA
Parvilucina amiantus (var.)	Lucina spB
Lucina radians	Lucina spC
Cavilucina trisulcatus	Lucina spE
Lyropecten nodosus	Lyropec nodo
Macrocallista maculata	Macrocal mac
Macrocallista nimbosa	Macrocal nim
Mactra fragilis	Mactra fragl
Mercenaria campechiensis	Mercen campe
Noetia ponderosa	Noetia pondr
Nucula proxima	Nucula proxi
Nuculana acuta	Nuculana acu
Pandora arenosa	Pandora bush
Pandora trilineata	Pandora tril
Papyridea soleniformis	Papyrid soln
Aequipecten gibbus	Pecten gibbu
Pecten muscosus	Pecten musco
Pecten raveneli	Pecten reven
Pitar fulminata	Pitar fulmin
Plicatula gibbosa	Plicat gibbo
Pododesmus rudis	Pododes rudi

Taxon	Abbreviation
Pteria colymbus	Pteria colym
Scapharca transversa	Scaphar tran
Semele bellastriata	Semele belli
Cavilucina trisulcatus	Sp 1
Mulinia lateralis	Sp 10
Arcinella cornuta (juv.)	Sp 13
Aligena texasiana	Sp 14
Ervilia concentrica	Sp 2
Macrocallista maculata	Sp 3
Transennella sp.	Sp 4
Abra aequalis	Sp 5
Montecuta floridana	Sp 6
Montecuta floridana (var.)	Sp 7
Cooperella atlantica	Sp 8
Ensitellops protexta	Sp 9
Spisula solidissima	Spisula soli
Spondylus ictericus	Spondyl ictr
Strigilla mirabilis	Strigil mira
Tagelus divisus	Tagelus pleb
Tellidora cristata	Tellidor cri
Tellina interrupta	Tellina inte
Tellina lintea	Tellina lint
Tellina magna	Tellina magn
Tellina spp.	Tellina spp
Thyasira trisinuata	Thyasira sp
Trachycardium muricatum	Trachy muric
Trachycardium egmontianum	Trachyc egmt
Trigonocardia media	Trigonoc med
Venericardia perplana	Veneric perp
Venericardia tridentata	Veneric trid
Verticordia ornata	Verticord sp
Macoma tenta	Macoma tenta
Macoma brevifrons	Tellina sp
Lyonsia floridana	Lyonsia flor
Periploma inequale	Periplom ine
Gastropods	
Crepidula fornicata	Crepid forni
Cerithium floridanum	Cerith flori
Turbo castaneus	Turbo castan
Modulus modulus	Modulus modu
Polinices lacteus	Polinic lact

Taxon	Abbreviation
Nassarius vibex	Nassarius A
Nassarius albus	Nassarius C
Terebra dislocata	Terebra disl
Epitonium novangliae	Epitonium B
Prunum apicinum	Marginel api
Bulla striata	Bulla striat
Conus stearnsi	Conus stearn
Strombus pugilis	Strombus pug
Turritella variegata	Turritel var
Crepidula plana	Crepid plana
Olivella mutica	Olivella pus
Oliva sayana	Oliva sayana
Crepidula aculeata	Crepid acule
Eupleura caudata	Eupleura cau
Olivella floralia	Olivella flo
Anachis avera similis	Anachis simi
Anachis avera semiplicata	Anachis semi
Cantharus cancellarius	Canthar canc
Nassarius albus (var.)	Nassarius B
Rubellatoma diomedia	Rubellit dio
Cavolina longirostris	Cavolina sp
Calyptraea centralis	Calyptr cent
Pyrene albella iontha	Pyrene albel
Natica canrena	Natica canre
Phalium granulatum	Phalium gran
Conus floridanus	Conus florid
Terebra concava	Terebra conc
Cancellaria conradiana	Cancellaria
Natica cf. N. pusilla	Natica sp
Polinices duplicatus	Polinic dupl
Acteon punctostriatus	Acteon punct
Calliostoma spp.	Calliostoma
Epitonium angulatum	Epitonium A
Marginella succinea	Marginel suc
Rubellatoma diomedia (var.)	Sp 15
Terebra cinerea	Terebra cine
Colubraria lanceolata	Colubrar lan
Cyphoma gibbosa	Cyphoma mcgi
Diodora meta	Diodora meta
Amaea retifera	Amaea retife
Cantharus cancellarius	Canthar tinc
Diodora cayenensis	Diodora cayn
Calliostoma euglyptum	Callios eugl

Taxon	Abbreviation
Sinum perspectivum	Sinum perspe
Atys caribaea	Atys caribae
Melanella intermedia	Melanel inte
Crassispira tampaensis	Crassisp tam
Fasiolaria hunteri	Fasiol hunte
Epitonium apiculatum	Epitonium C
Epitonium multistriatum	Epitonium E
Scaphopods	
Dentalium eboreum	Dental ebore
Cadulus carolinensis	Cadulus caro
Miscellaneus	
Encope spp. Fragments	Encope
Bivalve Fragments	Bivalve Frag
Limestone Fragments	Rock Frags
Gastropod Fragments	Gastro Frags
Coralline Algae	Calc Red Alg
Cupularid Bryozoan Zoaria	Bryozoa
Barnacle Fragments	Barnacles
Plagiobrissus grandis Fragments	Heart Urchin
Unknown Grains	Unknown
Coral Fragments	Coral
Lignitized Wood Fragments	Wood
Crustacean Exoskeleton Fragments	Crusta Frags
Peneroplid Foraminifera Tests	Peneroplids

APPENDIX L

MISCELLANEOUS VARIABLES MEASURED ON SEMIQUANTITATIVE SAMPLES (>2.38mm.)

Code Explanation

1 - Total sample weight*

2 - Total weight biogenic material

3 - Weight biogenic material 64.0mm.

4 - Weight biogenic material 15.85-64.0mm.

5 - Weight biogenic material 7.93-15.85mm.

6 - Weight biogenic material 2.38-7.93mm.

7 - Correction factor for bivalve counts 2.38-7.93mm.

8 - Correction factor for unidentified bivalve fragments and other biogenic grain types 2.38-7.93mm.

9 - Number of biogenic grains per 100 grams of biogenic material

*weights in grams

CODE	L111	L112	L113	L114	L121	L122	L123	L124	L131	L132	L133	L134	L141	L142	L143	L144
1	1015	824	1490	1219	314	142	197	100	89	130	172	95	111	199	111	88
2	573	482	689	700	314	142	197	100	89	130	172	95	111	199	111	88
3	47	44	103	101	-	-	-	-	-	-	-	-	-	-	-	-
4	116	58	77	100	12	-	2	2	-	2	32	-	6	44	3	-
5	91	79	109	103	26	10	19	9	7	13	24	8	13	39	16	11
6	321	301	455	417	276	131	177	89	80	115	116	87	91	116	93	78
7	4.05	1.98	3.15	3.22	4.08	3.64	5.10	3.78	2.03	4.22	4.24	1.95	2.14	4.03	1.95	1.96
8	4.05	1.98	3.15	3.22	4.08	3.64	5.10	3.78	2.03	4.22	4.24	1.95	2.14	4.03	1.95	1.96
9	1279	1129	1056	1330	4784	7173	5441	5637	4956	5792	3148	4076	2789	2453	3182	3532

Miscellaneous Variables Measured on Semiquantitative Samples (>2.38mm.)

L151	L152	L153	L154	L161	L162	L163	L164	L171	L172	L173	L174	L181	L182	L183	L184
136	132	245	178	167	153	152	100	56	27	37	49	61	83	20	31
136	132	245	178	167	153	152	100	56	27	37	49	61	83	20	31
-	-	74	-	-	-	12	-	-	-	-	-	-	43	-	-
28	18	32	10	12	27	54	20	6	-	4	6	9	18	-	3
22	21	28	18	42	27	21	17	17	10	8	11	20	6	6	10
86	94	112	150	113	90	65	63	33	17	26	33	32	17	13	19
1.99	2.04	3.91	4.08	2.38	2.15	1.31	1.36	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.99	2.04	3.91	4.08	2.38	2.15	1.31	1.36	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1908	2219	1360	2819	1607	1842	1129	1754	2061	2135	2578	2156	2055	632	1965	2005

L191	L192	L193	L194	L1101	L1102	L1103	L1104	L211	L212	L213	L214	L221	L222	L223	L224
10	10	15	16	6	4	5	5	442	483	655	452	440	406	404	280
10	10	15	16	6	4	5	5	442	483	655	452	440	406	404	280
-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-
-	-	5	1	-	-	-	-	60	49	39	61	61	101	55	43
2	2	1	4	-	-	-	-	43	66	65	63	80	57	63	32
8	8	9	11	6	4	5	5	347	367	551	328	287	247	286	206
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	4.29	4.32	8.34	4.17	4.35	4.16	4.50	4.13
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	4.29	4.32	8.34	4.17	4.35	4.16	4.50	4.13
3180	3390	2250	2410	4165	4446	4463	3227	2089	2061	2715	2127	2012	1566	2196	2544

L231	L232	L233	L234	L241	L242	L243	L244	L251	L252	L253	L254	L261	L262	L263	L264
243	340	329	268	258	163	145	126	79	77	98	94	107	83	81	69
243	340	329	268	258	163	145	126	79	77	98	94	107	83	81	69
13	41	49	-	39	-	8	-	-	-	-	7	-	-	-	-
2	37	39	18	10	1	2	11	11	6	5	3	12	-	-	2
35	38	32	39	27	26	15	13	6	4	13	7	15	14	7	18
193	224	210	211	183	136	119	103	63	67	81	78	80	70	74	49
4.22	4.28	4.23	3.85	4.00	4.23	4.11	4.21	2.00	2.04	3.95	2.16	1.68	1.93	2.04	1.00
4.22	4.28	4.23	3.85	4.00	4.23	4.11	4.21	2.00	2.04	3.95	2.16	1.68	1.93	2.04	1.00
2604	2260	1738	2776	2524	3603	3136	3164	2911	3039	3179	3113	2629	2944	3316	2166

L271	L272	L273	L274	L281	L282	L283	L284	L291	L292	L293	L294	L2101	L2102	L2103	L2104
37	64	47	44	26	244	187	42	46	21	11	20	2	1	2	3
37	64	47	44	26	244	187	42	46	21	11	20	2	1	2	3
-	-	-	-	-	181	79	-	-	-	-	-	-	-	-	-
3	5	-	2	2	16	13	7	20	-	-	-	-	-	-	-
7	28	9	7	2	14	6	3	10	3	1	8	-	-	-	-
27	31	38	35	23	33	39	32	17	18	11	11	2	1	2	3
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2513	1313	2798	2315	2779	475	731	2842	1030	2806	3726	1788	3462	5300	3465	4000

RL111	RL112	RL121	RL122	RL131	RL132	RL141	RL142	RL151	RL152	RL161	RL162	RL171	RL172	RL181	RL182
2942	2542	376	309	384	564	250	348	252	178	256	198	2405	1162	1445	2025
1386	1056	292	284	360	409	227	348	252	178	256	198	1713	986	1360	1703
19	41	-	-	-	-	-	-	-	-	-	-	335	303	346	334
262	88	63	8	33	21	2	4	1	1	2	3	579	313	311	465
245	127	26	45	47	53	20	15	22	19	36	21	216	131	175	320
870	800	203	231	280	335	203	331	229	159	218	173	584	239	528	584
8.92	8.35	4.25	4.58	5.46	4.50	4.68	4.20	4.25	4.35	4.36	4.04	4.51	4.38	4.13	4.08
8.78	7.85	4.25	4.58	5.46	4.50	4.68	4.20	4.25	4.35	4.36	4.04	4.51	4.38	4.13	4.08
1965	2286	3773	4526	4375	4359	5487	6557	5125	4956	6041	4291	664	759	774	800

RL191	RL192	RL1101	RL1102	RL1111	RL1112	Code Explanation
1892	1909	1687	1320	1598	1362	1 - Total sample weight.
1772	1727	1580	1241	1529	1301	2 - Total weight biogenic material.
123	134	195	141	116	298	3 - Weight biogenic material >64.0mm.
583	619	495	356	499	291	4 - Weight biogenic material 15.85-64.0mm.
370	291	322	236	314	262	5 - Weight biogenic material 7.93- 15.85mm.
696	683	568	508	600	450	6 - Weight biogenic material 2.38-7.93mm.
8.61	8.28	4.34	4.40	4.42	4.38	7 - Correction factor for bivalve counts 2.38-7.93mm.
8.61	8.28	4.34	4.40	4.42	4.38	8 - Correction factor for unidentified bivalve fragments and other biogenic grain types 2.38-7.93mm.
915	1037	928	1084	1105	870	9 - Number of biogenic grains per 100 grams biogenic material.

above weights in grams

VITA

Macomb Trezevant Jervey was born in Omaha, Nebraska, on January 25, 1941, the son of William Trezevant Jervey and Virginia Hilton Jervey. He moved shortly thereafter to West Orange, New Jersey, where he attended primary school. He graduated, in 1959, from the Pingry School, a college preparatory school in Elizabeth, New Jersey. In the fall of that year he entered Rutgers University, New Brunswick, New Jersey, from which he graduated in 1963 with an A.B. degree. He entered graduate school at Princeton University in the fall of 1963 but withdrew the following summer to accept a position with Shell Oil Company in New Orleans, Louisiana, in the fields of micropaleontology and subsurface geology until the summer of 1969. At that time he began graduate studies toward a Ph.D. degree at Louisiana State University graduating in August, 1974.

As an undergraduate Macomb Jervey was honored for excellence in geology as a recipient of a Kennecott Scholarship and as a Henry Rutgers Scholar in his senior year. At Louisiana State University he was awarded a grant for dissertation research by the Oceanographic Section of the National Science Foundation. He was also honored to receive a National Defense Education Act Fellowship and a Dissertation Year Fellowship.

Macomb Jervey is a member of the American Association for the Advancement of Science, the Geological Society of America, and the Society of Economic Paleontologists and Mineralogists.

In 1963 Macomb Jervey married Faith Louise Lagay, the daughter of William and Esther Lagay of Long Branch, New Jersey. Macomb and Faith Jervey have one daughter, Allyson McCrea Jervey.

EXAMINATION AND THESIS REPORT

Candidate: Macomb Trezevant Jervey

Major Field: Geology

Title of Thesis: Transportation and Dispersal of Biogenic Material in the Nearshore Marine Environment.

Approved:

Bob F. Perkins
Major Professor and Chairman

James L. Ingraham
Dean of the Graduate School

EXAMINING COMMITTEE:

Bob F. Perkins

Prentiss F. Schilling

Donald H Kupfer

Donald R. Lowe

Date of Examination:

March 6, 1974